Study of the Anatomical Variations of the Liver in Human

Dissertation submitted for

M.D Anatomy Branch V Degree Examination,

The Tamil Nadu Dr. M.G.R. Medical University

Chennai, Tamil Nadu.

May – 2018

DECLARATION

I hereby declare that the dissertation entitled "Study of the Anatomical variations of the liver in Human" is a bonafide research work done by me under the supervision of Dr.J. Suganthy, Professor of Anatomy, Christian Medical College, Vellore, in partial fulfilment of the requirements for the MD Anatomy examination (Branch V) of the Tamil Nadu Dr. M.G.R. Medical University, Chennai to be held in May 2018.

Name: Dr. Haobam Rajajee Singh

MD Anatomy (Branch V)

CERTIFICATE

This is to certify that "Study of the Anatomical variations of the liver in Human" is a bonafide work of **Dr. Haobam Rajajee Singh** in partial fulfilment of the requirements for the M.D Anatomy examination (Branch V) of The Tamil Nadu Dr. M.G.R. Medical University to be held in May 2018.

Suganthy

Dr. J. Suganthy, M.S, D.N.B, Ph.D

Head of Deparment and Guide,

Department of Anatomy,

Christian Medical College,

Vellore, Tamil Nadu.

CERTIFICATE

This is to certify that "Study of the Anatomical Variations of the Liver in Human" is a bonafide work of **Dr. Haobam Rajajee Singh** in partial fulfillment of the requirements for the M.D Anatomy examination (Branch V) of The Tamil Nadu Dr. M.G.R. Medical University to be held in May 2018.

Suganthy

Dr. J. Suganthy, M.S, D.N.B, Ph.D
Professor and Head,
Department of Anatomy,
Christian Medical College,
Vellore, Tamil Nadu.

Dr. Anna. B. Pulimood, M.D, Ph.D
Principal,
Christian Medical College,
Vellore, Tamil Nadu.

URKUND

Urkund Analysis Result

Analysed Document: Liver anomalies 28th August 2017.doc (D30332097)
Submitted: 2017-09-01 12:44:00
Submitted By: drrajhaobam@cmcvellore.ac.in
Significance: 5 %

Sources included in the report:

Kiran Sidana Ch-3.pdf (D21245248)
595a1ddba4c96_Anatomy-2_Version_1.docx (D29561914)
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5385700/
https://www.hindawi.com/journals/crim/2013/604513/

Instances where selected sources appear:

30

TABLE OF CONTENTS

ACKNOWLEDGEMENT

- I thank God Almighty for helping me finish this thesis with His presence in each and every step.
- I am grateful to the Institutional Review Board (IRB) of Christian Medical College, Vellore for giving me the permission and funding for this project.
- I sincerely thank Dr. Suganthy J, my guide for entrusting and encouraging me to start this study and for being an inspiration and supporting and helping me all the time.
- Dr. Reetu Amrita John, Assistant professor and Dr. Anu Eapen, Professor, Department of Radiology for helping me in getting the images and explaining the images
- Dr. Manbha Rymbai, Assistant surgeon, Department of Hepatopancreato biliary surgery for accepting the concept
- Dr. Devakumar Devadhas, Associate professor, Department of Nuclear Medicine for his guidance
- Dr. Pauline Shanthi, Assistant professor, Department of Anatomy for her guidance and help
- Mr. Prakash R, Senior demonstrator, Department of Biostatistics for helping me in calculation of sample size and Ms. Hepsy.Y.S for helping me in analysis of the thesis data
- All Associate Professors and Assistant professors for their help in times of need
- All co - postgraduates for their valuable suggestions, help and encouragement
- Mr. K. R. Gopi and Mr. Balakrishnan, technicians, for all the help during the dissection work for the thesis

- To all non- teaching staff in the Department of Anatomy – Mr. S. Thirumurugan (late), Mr. Antonyswamy, Mr. R. Gopi, Mr. Sanmughan, Mr. Dhandapani, Mr. Babu, Mr. Collin, Mr. N. Narayanan for their help with arrangement of the liver specimens and support all the time
- Mr. V. Gopinath (Secretary) and Mr. G. Rajkumar (Artist) in the Department of Anatomy for their timely help
- To all generous volunteers who donated bodies
- Finally I thank all my family members for their constant support, encouragement and prayers

INTRODUCTION

1. INTRODUCTION

The liver is the largest abdominal organ. It occupies the right hypochondrium, epigastrium and a small part of the left hypochondrium. It has been divided into the right, left, caudate and quadrate lobes based on the surface peritoneal and ligamentous attachments.[1] The right and left lobes are partitioned by falciform ligament anteriorly and by the fissure for ligamentum venosum and fissure for ligamentum teres inferiorly. Functionally, Cantlie's line which runs between the fossa for gall bladder and inferior vena cava on the diaphragmatic surface and divides the liver into right and left lobes.[2] This corresponds to middle hepatic vein. The structures present at the hilum of the liver include the hepatic artery, portal vein and the bile duct. The branching patterns of blood supply and biliary drainage in the liver form the lobes and further subdivision form the segments or sectors of the liver.[1] According to Couinaud's division of the liver, there are eight functional segments (I to VIII). Distribution of the portal venous system and the hepatic veins forms the basis of this division.[3]

In addition to the right, left, caudate and quadrate lobes, accessory lobes and fissures have been described. It has been found out in Indian population, that accessory lobes are present in 10% of the population.[3] Various other anomalies like quadrate lobe with complete transverse fissure dividing the lobe into a superior and an inferior lobe, pons hepatis connecting the left lobe with the quadrate lobe,[3] hypoplasia of right lobe of the liver[4] have been reported. A defect in the development or overgrowth of the tissues will contribute to a malformed liver. The mini accessory

lobe might be mistaken for a lymph node due to its small size and removed during the surgeries. Torsion of the vascular pedicle may require urgent manipulation.[3] Presence of accessory fissures are the potential sources of diagnostic errors during imaging. It may be mistaken for a liver cyst, hematoma or abscess when there is a collection of fluid in these fissures. Metastatic tumour cells getting lodged into these spaces may mimic intrahepatic focal lesions. Knowledge of such possible variations is thereby important during radiological investigation and surgery.[3]

The liver receives upto about 25% of the cardiac output. It is supplied by hepatic artery which is a branch of coeliac trunk and contributes to about 25% to 30 % of the blood supply to the liver. It also gets blood supply from the portal vein which contributes to the remaining 70%-75%. The arterial and the venous blood ultimately gets mixed up in the sinusoids of the liver and through the right, middle and left hepatic veins, the venous blood drain into the inferior vena cava.[5]

Variations in the extrahepatic branching pattern of the hepatic artery and portal vein have been reported earlier. The common hepatic artery arises from celiac trunk and gives off the right gastric, the right gastroduodenal and the proper hepatic artery. The proper hepatic artery gives off the right hepatic, left hepatic and middle hepatic arteries supplying the right, left and quadrate lobe of the liver respectively.[6] Extrahepatic arterial variations have been classified into 10 types by Michael.[7] Kamath, reported that in 35% of Indian population, the middle hepatic artery supplying the quadrate lobe of the liver was given extrahepatically. In 17.5% the common hepatic artery trifurcates into gastroduodenal, right and left hepatic arteries with the absence of hepatic artery proper and in 25% aberrant hepatic arteries were

present.[6] But there is a paucity of literature in the intrahepatic branching pattern of the hepatic artery.

The portal vein begins at the level of the second lumbar vertebra and is formed by the union of the superior mesenteric and splenic veins.[1] It is approximately 8cm long and lies anterior to the inferior vena cava and posterior to the neck of the pancreas. It ascends behind the first part of the duodenum, the common bile duct and gastroduodenal artery. It enters the right border of the lesser omentum, ascends anterior to the epiploic foramen to reach the portahepatis. It then divides into right and left main branches which accompany the corresponding branches of the hepatic artery into the liver.[1] Guler et al. (2013) reported that 12.6% donors have portal vein variations.[8] Preoperative assessment of the portal vein system is essential for safe hepatectomy.[9,10] With the growing popularity of complex hepatobiliary surgical and percutaneous procedures, including trisegmentectomy, portal vein embolization, and transjugular intrahepatic portosystemic shunts (TIPS), the detection and recognition of portal vein variants are increasingly relevant.

A reduction in iatrogenic complications during hepatobiliary surgeries can be achieved with the knowledge of the variation of hepatobilary system. Though there are a few studies available regarding the intrahepatic branching pattern of the hepatobilary system in other population, there is no data available for Indian population.

AIMS AND OBJECTIVES

2. AIM AND OBJECTIVES

Aim:

To describe the anatomical variations of the hepatic artery and portal vein within the liver in terms of branching pattern and determine the frequency of each pattern.

Objectives:

- To determine the gross anatomical variations of the liver
- To determine the variation in the branching pattern of hepatic artery and portal vein by modified corrosion casting technique
- To determine the variation in the branching pattern of the hepatic vasculature by 3D reconstruction of contrast enhanced computed tomography (CECT)

LITERATURE REVIEW

3. LITERATURE REVIEW

The liver is located in the right hypochondrium, epigastrium and extends to the left hypochondrium. Based on the surface peritoneal and ligamentous attachments, the liver can be anatomically divided into the right, the left; the caudate and the quadrate lobes.[1] The part of the caudate lobe adjacent to the inferior vena cava is known as the paracaval portion and the part which is adjacent to the fissure for ligamentum venosus is known as Spiegel's lobe.[11] The caudate lobe has caudate process and papillary process.[11]

3.1 Fissures of the liver:

Knowledge of the fissures of the liver is essential for understanding liver surgery. The liver has 3 major fissures and 3 minor fissures.The three major fissures are the main, left and right portal fissure. They are not visible on the surface. They run through the liver parenchyma and harbour the three main hepatic veins (Figure 3.1). Three minor fissures are the umbilical fissure, the venous fissure and the fissure of Gans. They are visible on the liver surface.[1]

Major fissures:

Main portal fissure:

The main fissure extends from the tip of the gallbladder back to the midpoint of the inferior vena cava and contains the middle (main) hepatic vein. It separates the liver into right and left hemi-livers. Segments V and VIII lie to the right and segment IV to the left of the fissure.[1]

Left portal fissure:

The left fissure divides the left hemi-liver into medial (anterior) and lateral (posterior) sectors. It extends from the midpoint of the anterior edge of the liver between the falciform ligament and the left triangular ligament to the point which marks the confluence of the left and middle hepatic veins. It contains the left hepatic vein and separates the left anterior and left posterior sectors: segment III lies anteriorly and segment II lies posteriorly.[1]

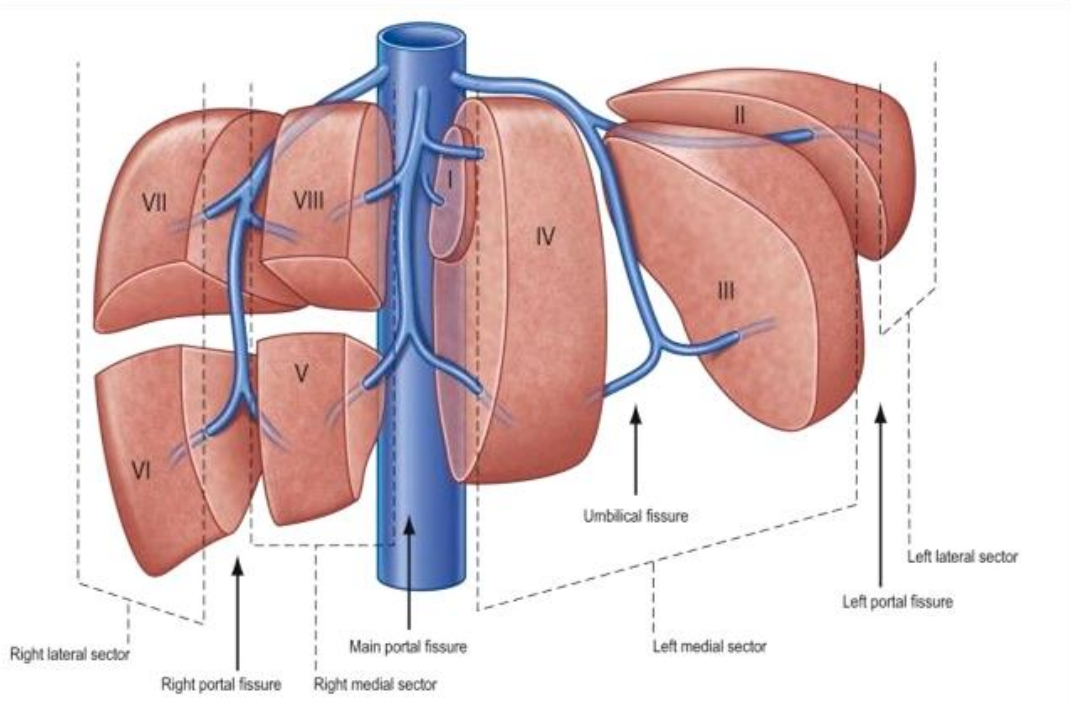


Figure 3.1 showing segments of liver. The picture is reproduced from the Gray's Anatomy 40th Edition, Pg. No. 1165

Right Portal fissure:

The right portal fissure divides the right hemi-liver into lateral (posterior) and medial (anterior) sectors. This fissure contain the right hepatic vein. It divides the right anterior sector (segments V and VIII) from the right posterior sector (segments VI and VII). The right portal fissure marks the thickest point of liver parenchyma which is commonly transected during liver resection.[1]

Minor fissures:

Umbilical fissure:

The umbilical fissure separates segment III from segment IV and contains a main branch of the left hepatic vein (the umbilical fissure vein). It is marked by the attachment of the falciform ligament. It is often avascular and can be divided safely with diathermy during a surgical approach. In addition to the umbilical portion of the left portal vein it also contains the final divisions of the left hepatic duct and the left hepatic artery branches. The umbilical portion of the left portal vein is an important landmark. Access to this vein and mobilization of the left portal vein are essential steps in surgery for hilar cholangiocarcinoma. A knowledge of the arrangement of the portal vein, hepatic artery and bile duct within the umbilical fissure is essential for live donor liver transplantation (LDLT).[1]

Venous fissure:

The venous fissure is a continuation of the umbilical fissure on the under surface of the liver and contains the ligamentum venosum. It lies between the caudate lobe and the left lobe.[5]

Fissure of Gans:

The fissure of Gans lies on the undersurface of the right lobe of the liver behind the gallbladder fossa. It often contains the portal pedicle to the right posterior sector and is thought to correspond to the right fissure as it relates to the separation of the sectors of the liver.[1]

3.2 Segments of the liver: **(Figure 3.1)**

According to Couinaud's division of the liver, there are eight functional segments (I to VIII). Distribution of the portal venous system and the location of hepatic veins forms the basis of this division.[1]

Segment I

Segment I corresponds to the anatomical caudate lobe and lies posterior to segment IV. It receives vessels independently from the left and right portal veins and hepatic arteries, and it drains independently into the inferior vena cava by multiple small branches. The bile ducts draining the segment are closely related to the confluence of the right and left hepatic ducts.

Segments II

Segment II lies postero-lateral to the left fissure. It drains into the left hepatic vein.

Segment III

Segment III lies between the umbilical fissure and the left fissure, it drains into the left hepatic vein.

Segment IV

Segment IV lies between the umbilical fissure and the main fissure, The main venous drainage segment is into the middle hepatic vein; the segment can also drain into the left hepatic vein through the vein of the falciform ligament.

Segment V

Segment V lies between the middle and the right hepatic veins. Venous drainage is into the right and middle hepatic veins.

Segment VI

Segment VI lies posterior to the right portal fissure. Venous drainage is normally into the right hepatic vein.

Segment VII

Segment VII lies behind the right hepatic vein. The venous drainage is into the right hepatic vein.

Segment VIII

Segment VIII is the superior part of the right anterior sector.

3.3 Variation in liver morphology

The segmental anatomy of the liver has been extensively researched, but there are very few studies which have dealt with surface variations of the liver.[12] Variations in the liver morphology can be either congenital or acquired.

The liver starts its organogenesis early during 3rd week of intrauterine life and develops more rapidly. In spite of its complex development, developmental anomalies are rare.[13] The congenital anomalies of liver can be divided into anomalies due to defective development and anomalies due to excessive development.[13] It was described that the hepatic malformations are common in perinatal age group and liver undergoes reformation postnatal. Accordingly all fissures and lobes of liver should disappear during postnatal.[14] There are many kinds of described congenital abnormalities of the liver. It could be:[15,16]

a) agenesis of lobes
b) absence of its segments
c) deformed lobes
d) accessory lobes
e) lobar atrophy
f) presence of only one lobe
g) presence of multiple lobes
h) hypoplastic lobes
i) peduncular lobes
j) lobes without division
k) Riedel's lobe
l) Transposition of the gall bladder

Acquired variations in liver could be due to the pressure given by diaphragm, peritoneal ligaments and other organs in relation with liver so developed during lifetime of a person.[11]

Netter classified the morphological variations of the liver into 7 types as follows:

Table 3.1. Netter's classification of morphological variations of liver

Types	Description
Type1	Normal
Type2	Very small left lobe, deep costal impressions
Type3	Complete atrophy of left lobe
Type4	Transverse saddle like liver, relatively large left lobe
Type5	Tongue like process of right lobe
Type6	Very deep renal impression and corset constriction
Type 7	Diaphragmatic grooves

Agenesis of liver lobes:

Congenital agenesis of liver lobe affects the left lobe more than the right.[17–19] Aktan et al. reported absence of the left liver lobe in 11 cases out of 383 CT images.[15] Agenesis of the right lobe of the liver is a rare anomaly and only 42 cases have been reported earlier.[20] It occurs slightly more often in men. In patients with agenesis of the right lobe of the liver, the right hapatic vein will be absent.[19,21] Agenesis of the right lobe might be associated with billiary tract disease, portal hypertension, and other congenital anomalies.[18]

Morphological variations of Right lobe:

Agenesis and atrophy of the right hepatic lobe has been reported ealier by various authors.[17–20,22,23,24] Hypoplasia of the right lobe of the liver was reported by Shankar and Rabi (2005) with other associated anomalies like persistent right

umbilical vein.[4] Fissures and accessory lobes including Riedel's lobe are the other variations associated with the right lobe.

Morphological variations of Left lobe:

Morphological variations of left lobe include hypertrophy of left lobe, hypoplasia of left lobe and presence of fissures.[11] Enlargement of left lobe associated with agenesis of right lobe was reported by Nikam and Kitture on radiological study.[25] Shankar and Rabi reported enlargement of left lobe with hypoplasia of right lobe in a cadaver.[4] Abnormal 'L' shaped large left lobe, with the shift of quadrate lobe and fissure for ligamentum teres to right was noticed by Saritha et al.[14] Hypoplastic left lobes were reported in 3.44% specimens by Vinnakota and Jeyasree.[26] Liver with elongated left lobe is otherwise called as Beaver's lobe or lingual process or Netter's type 5 variation. Such extremely long left lobe was reported by various authors including Nayak et al. who reported in one liver out of 55[27] and 2 out of 50.[14] Elongated left lobe was reported in 4% by Mamatha et al.[28] and in 1.72% by Vinnakota and Jayasree.[26] Chaudhari et al. reported elongated left lobe in 12.5% of the 80 livers studied.[12] Shivarama and Kumar reported a lingular prolongation of the left lobe capping the spleen.[29]

Morphological variations of Caudate lobe:

Phad et al.(2014) reported morphological variations of caudate lobe in 30% of the 80 livers studied. They found enlargement of caudate process and paracaval portion in 10% of the specimens studied. Enlargement of papillary process (Spiegel's

lobe or Couinaud's segment) was seen in 5%. Notch or fissure separating papillary process from rest of the caudate lobe was seen in 2.5%.[11]

Abraham et al. observed vertical fissure extending upwards from lower border of caudate lobe in 5.1% and also oblique fissures in caudate lobe.[30] In addition, he also reported prominent papillary process in 1.81% cases and absence of papillary process in 33%.

Various shapes of the caudate lobe were observed. Phad et al. observed variations in shape of the caudate lobe in 12.5% of specimens including streak shaped hypoplastic caudate lobe in one specimen.[11] Sarala et al.(2015) observed rectangular shaped caudate lobe in 58%, pear shaped in 10%, irregular in 20%, triangular in 8%, others (square, heart shape, inverted pear) in 4% of the livers studied.[31] Chavan and Wabale observed rectangular shaped caudate lobe in 48%, pear shaped in 26%, oval in 14%, square 6%, triangular in 4% and inverted flask shaped in 2% out of 50 livers studied.[32] Abraham et al reported rectangular shaped caudate lobe in 57.6%, bicornuate in 12%, pyriform in 18.6%, inverted pyriform in 3.4%, globular or heart shaped in 10.2% out of 59 livers studied.[30]

Accessory fissures and accessory lobes in the caudate lobe has been described earlier. Vinnakota and Jayasree reported accessory fissures and accessory lobes in the caudate lobe in 8 specimens out of 31 liver specimens studied.[26] Singh reported an accessory caudate lobe associated with hypoplastic left lobe of liver.[33]

Absent caudate lobe was reported by Aktan et al.[15]

Morphological variations of Quadrate Lobe:

Phad et al. reported morphological variations in quadrate lobe in 12.5% of specimens. These include presence of pons hepatis, i.e segment of hepatic tissue connecting quadrate lobe to left lobe over the fissure for ligamentum teres hepatis, presence of horizontal fissures and variation in shape.[11] Presence of accessory lobes in the quadrate lobe, accessory fissures, various shapes ranging from triangular to irregular, and also various size from very narrow to ill-defined and pons hepatis was noted by Vinnakota and Jayasree.[26] Abnormal quadrate lobe in the form of absence of quadrate lobe, deeply buried, transverse fissure and fusion with right and left lobe was also observed.[28]

Pons hepatis was reported in 4% of the livers by Saritha et al. and 14% by Khedekar and Hattangdi.[34] Vinnakota and Jayasree observed accessory fissures in quadrate lobe. They have reported a complete transverse fissure dividing the quadrate lobe into a superior and an inferior lobe.[26] Saritha et al. also reported such a complete transverse fissure in the quadrate lobe. In addition, they reported a mini accessory quadrate lobe in 2%.[14] Absence of quadrate lobe has also been reported in one liver.[35]

Morphological variations of surface of liver

Costal impressions of the liver were noted in previous studies. Liver with diaphragmatic impression (Netter's Type 7) has been reported by Vinnakota and Jeyasree.[26] Deep renal impressions with corset constrictions were reported by Saritha et al. in 4% livers studied.

In addition to the surface variations, notches along the inferior border were reported.[36]

Accessory fissures of liver:

Accessory fissures were noted in the right, left, caudate and quadrate lobes of the liver by various authors. Saritha et al. reported accessory fissures in 30% and Khedekar and Hattangdi in 42% of the livers studied.[14,35] Khedekar and Hattangdi also have reported the number of fissures ranged from 1-5 in each liver. Accessory fissures in the right lobe[26,28], in the left lobe[26], fissure extending over postereo-superior surface[28] and between caudate process and duodenal impression[26] have been reported.

Accessory lobes of the liver

Accessory lobe of the liver was a rare congenital anomaly found incidentally at autopsy or laparotomy. They are commonly found on the undersurface of the liver and seen on the gallbladder surface, hepatogastric ligament near umbilicus, adrenal gland, pancreas and the thoracic cavity.[37] Sato et al. in a series of 1800 laproscopices described that the accessory lobe was a congenital anomaly found in approximately 0.7%.[38] Maharana reported in 4.76% of cases, Saritha et al., in 16% and Muktyaz et al. in 14.6% of cases.[14,37,39]

Reidel's lobe:

Riedel's lobe is described as an inferior, tongue-like projection of the anterior border of the right lobe of the liver to the right of the gallbladder.[40] It was first described by Corbin in 1830 and it was defined by Riedel in 1888, as a ''round tumor on the anterior side of the liver, near the gallbladder, to its right''.[41] The incidence of Riedel lobe is approximately 25% in 20-45 year-olds and 60% in 45-65 year-olds, with female: male ratio being 3:1.[42] It may be clinically confused with an abdominal mass or pathological hepatomegaly.[43] The complications of Riedel's lobe include lobar torsion, mass effect induced obstruction, interference with laparoscopic surgical procedures and unnecessary imaging.[42]

Types of accessory lobes:

The accessory lobes can also be classified into three types, based on the biliary drainage pattern.[44]

In **type 1**, the duct of the accessory lobe drains into an intra–hepatic bile duct of the normal liver;

in **type 2**, the duct of the accessory lobe drains into an extra–hepatic bile duct of the normal liver, and

in **type3**, the accessory lobe and the normal liver have a common capsule and the bile duct of the accessory lobe drains into an extra–hepatic duct.

3.4 Vascular system of Liver

The liver receives its blood supply from the hepatic artery which is a branch of coeliac axis and through the portal vein which is formed by the joining of splenic and superior mesenteric vein.[5]

Preoperative assessment of the hepatic artery, portal vein and bile duct is essential for safe hepatectomy.[9,10] In living donor liver transplantation, careful manipulation of the vasculobiliary system is critical to avoid causing injury to the biliary duct, portal vein and hepatic vein in the residual liver and/or the graft.[10,45,46,47] Prompt identification of anatomical anomalies can help the surgeon to avoid postoperative complications.

Hepatic Artery

The hepatic artery is a branch of the coeliac trunk. In adults the hepatic artery is intermediate in size between the left gastric and splenic arteries. In foetal and early postnatal life, it is the largest branch of the coeliac axis.[1] From the coeliac trunk to the origin of the gastroduodenal artery, it is called as common hepatic artery, and from that point to its bifurcation it is called as proper hepatic artery.[1] Within the free border of the lesser omentum the hepatic artery is medial to the common bile duct and anterior to the portal vein. The branches of the hepatic artery are right gastric, gastroduodenal and cystic branches. At the porta hepatis it divides into right and left branches.[1]

The right hepatic artery divides into an anterior division supplying segments V and VIII, and a posterior division supplying segments VI and VII. In addition, the

anterior division often gives a branch to segment I and the gallbladder. The segmental arteries are end-arteries although some collateral circulation may occur.[1] The right hepatic artery usually crosses posterior to the common hepatic duct and therefore the right hepatic artery is involved in bile duct cancer earlier than the left hepatic artery. Occasionally the right hepatic artery crosses anterior to the common bile duct and therefore, may be injured in surgery of the common bile duct.[1]

The cystic artery is a branch of the right hepatic artery which is given off inside the Calot's triangle. Inside the triangle it bifurcates into superficial and deep branches which enter the neck or body of the gallbladder.[48] Various studies have reported that the cystic artery may arise from other sources like common hepatic artery or proper hepatic artery. Aristotle reported that in 40 livers which he dissected, cystic artery arose from right hepatic artery in 92.5%, proper hepatic artery in 5% and from common hepatic artery in 2.5%.[48] In addition to this, Williams et al. reported that cystic artery may arise from left hepatic artery, gastroduodenal trunk, superior pancreaticoduodenal artery and superior mesenteric artery.[49] Balija et al. reported that the prevalence of cystic artery arising from the left hepatic artery is 1%.[50] Nowak et al reported that the cystic artery may also arise from the right gastric artery and celiac trunk.[51] Double cystic artery has been reported in 15% - 25% of patients by Hugh et al. and in 12.2% during laparascopic cholecystectomy by Ding et al.[52,53]

The left hepatic artery divides into two sub-branches; medial and lateral segmental arteries. The medial segmental artery supplies the quadrate lobe and anterior region of the left lobe. The lateral segmental artery further divides into superior and inferior divisions to supply the left lobe of liver.[54]

According to Kamath, a typical 'normal' hepatic artery divides into three main branches - the right hepatic, the left hepatic and the middle hepatic supplying the right, left and quadrate lobe of the liver respectively.[6] The middle hepatic artery supplying the quadrate lobe is otherwise called as artery to segment IV.

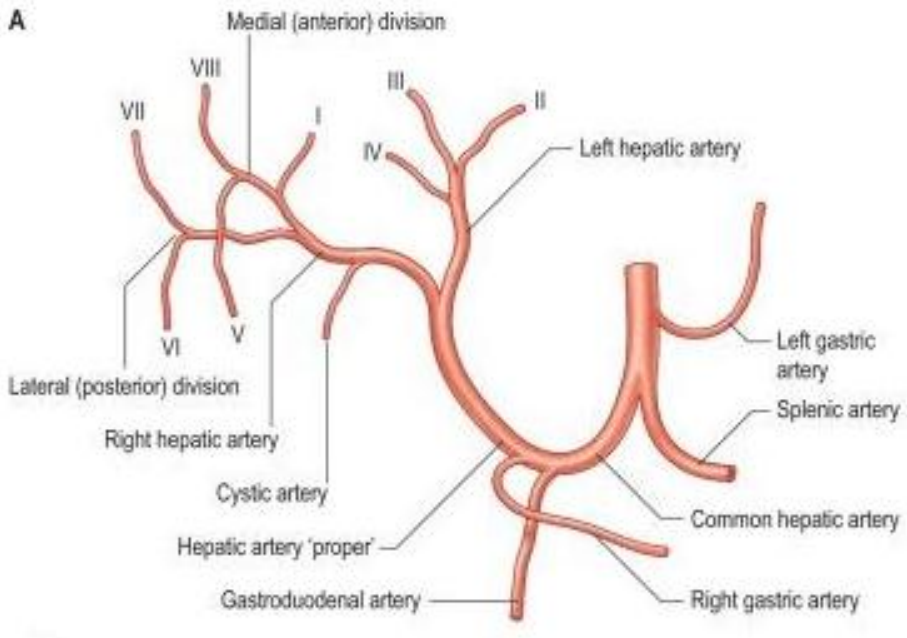


Figure 3.2 showing the branches of hepatic artery. The picture is reproduced from Gray's Anatomy 40th Editon Pg.No.1169.

Aberrant hepatic artery

If the hepatic artery arises from other than the coeliac trunk, it is known as 'aberrant hepatic artery'. It is of two types - accessory and replaced. The term ‘accessory’ hepatic artery is used if one hepatic artery arises from the coeliac trunk and there is an additional artery from other sources. When the normal right or left hepatic artery arising from coeliac trunk is missing and the replaced vessel coming from another source supplying the right or left lobe, then it is termed as a ‘replaced’ right or left hepatic artery [55]

Variations in the origin and branching patterns of hepatic artery are quite common. Congenital anomalies of the hepatic arterial supply are thought to occur because of the persistence of vitelline arteries during embryologic development.[56]

Anatomical variations of the hepatic arteries are of considerable importance in liver transplants, laparoscopic surgery, radiological abdominal interventions and penetrating injuries to the abdomen.[57] Rela et al. observed that the frequency of iatrogenic injury to hepatic artery rises in presence of aberrant hepatic arteries.[58]

Michel's described the hepatic arterial anatomy and its variations after 200 cadaveric dissections and identified 10 types of hepatic arterial anatomy (Table 3.2).[55] Hiatt et al. in 1994 modified Michel's classification and described 6 subtypes as it is difficult to distinguish between accessory and replaced hepatic arteries by angiography. Further, other authors including Adachi in 1928 and Abdullah in 2006 classified hepatic artery variations.

Table 3.2 Hepatic artery variations according to Michel's and Hiatt's classification

Description	Michel's classification	Hiatt's classification
RHA,MHA and LHA arise from CHA	Type I	Type I
Replaced LHA from the LGA	Type II	Type II
Replaced RHA from the SMA	Type III	Type III
Replaced RHA and LHA	Type IV	Type IV
RHA,MHA; and LHA arise from CHA; accessory LHA from the LGA	Type V	Type II
RHA,MHA and LHA arise from CHA; accessory RHA from SMA	Type VI	Type III
Accessory LHA from LGA and accessory RHA from SMA	Type VII	Type IV
Replaced RHA and Accessory LHA	Type VIII	Type IV
Entire hepatic trunk arise from SMA	Type IX	Type V
Entire hepatic trunk arise from LGA	Type X	NOD
CHA directly originating from the aorta	NOD	Type VI

RHA - Right hepatic artery, MHA - Middle hepatic artery, LHA - Left hepatic artery, CHA - Common hepatic artery, LGA - Left gastric artery, SMA - Superior mesenteric artery; NOD - Not otherwise described.

The most common variations are a replaced right hepatic artery arising from the superior mesenteric artery in 10–15% of cases and a left hepatic artery originating from the left gastric artery in 3–10% of patients.[55,59]

Kamath mentioned that out of the 40 cadavers studied, text book description of common hepatic artery originating from celiac trunk and dividing into right and left hepatic artery, and sometimes middle hepatic artery was seen in 30 (75%) cases only. He reported aberrant hepatic arteries in 25% of cases.[6]

Ugurel et al. reported that either coeliac trunk or hepatic artery variation was present in 50 out of 100 patients studied using multidetector CT angiography.[60] A

normal hepatic arterial system has been reported in 51–80% of cases in studies conducted using digital substraction angiography.[61,62]

Ramanadham et al. demonstrated a retroportal replaced right hepatic artery originated from the superior mesenteric artery and a replaced left hepatic artery originated from the left gastric artery.[63]

In a prospective investigation done in 1,081 donor cadaveric livers, Lopez-Andujar et al. reported the classical pattern in 30% of the livers. The most common variant was a replaced left hepatic artery arising from the left gastric artery (9.7%) followed by a replaced right hepatic artery arising from the superior mesenteric artery (7.8%).[64]

Sureka et al. did a retrospective review of multidetector CT abdominal angiography scans performed in patients between January 2012 and February 2013. A total of 600 patients were evaluated. In their study, normal origin of right hepatic artery from hepatic artery proper was seen in 79.6% patients. Replaced origin of right hepatic artery was seen in 15.16% cases and accessory origin of right hepatic was seen in 5.16% cases. Left hepatic artery originated from hepatic artery proper in 81.5% patients. Replaced left hepatic artery origin was seen in 10.8% cases and accessory left hepatic artery origin in 7.6% cases.[65]

In cadaveric dissections also, aberrant hepatic arteries have been reported. Suganthy et al reported in a case of multiple vascular variations of splanchnic branches of abdominal aorta, both accessory and replaced right hepatic artery and replaced left hepatic artery.[66] Yan et al. reported both replaced right and left hepatic artery supplying a liver.[67]

Covey et al. (2002) used digital subtraction angiography among 600 patients. In their study, in two patients, gastroduodenal artery arose from the celiac axis and the proper hepatic artery stemmed as the first branch of the superior mesenteric artery.[68]

In a study done in a total of 19,013 patients, 81% of cases displayed normal anatomy. A replaced right hepatic artery arose from the superior mesenteric artery in 3.7% of cases, while a replaced left hepatic artery stemmed from the left gastric artery in 3% of cases. Both replaced right and left hepatic arteries were found in 0.8% of cases, while an accessory left hepatic artery and an accessory right hepatic artery were present in 3.2% and 1.6% of cases respectively.[69]

Shukla et al. reported replaced right hepatic artery in 11-21% of cases and replaced left hepatic artery in 3.8-10% of cases, while accessory right hepatic artery and left hepatic artery have a frequency of 0.8-8%.[70]

Rare anomalies that are not consistent with any type described under Michel's and Hiatt's classifications can also be seen. Trifurcation of common hepatic artery into gastroduodenal, right and left hepatic arteries was seen in 17.5% cases. Hepatic artery proper was absent in these cases.[6] Ugurel et al. reported a right hepatic artery originated from the middle colic artery and another from the abdominal aorta and left hepatic artery arising from the common hepatic artery.[60] A replaced right hepatic artery that originated from the aorta was also reported by Koops et al.[71] Common hepatic artery along with the left gastric artery forming a separate trunk called as the hepatogastric trunk has also been reported.[72] Takeishi et al. reported a middle hepatic artery originating either from the gastroduodenal artery or common hepatic artery; a replaced right hepatic artery originating from the dorsal pancreatic artery and a right

posterior branch originating from the common hepatic artery. They also reported artery to segment III directly originating from the common hepatic artery.[73]

Artery to Segment IV

Normally, the artery supplying segment IV arises from left hepatic artery.[1,54] On contrary, various studies have mentioned that the incidence of artery to segment IV arising from right hepatic artery was more than the left. Table 3.3 shows the reports by various authors regarding the origin of artery to segment IV. According to Kamath, it was given off extrahepatically in 35% cases and from the right hepatic artery in 15%, left hepatic artery in 10% and hepatic artery proper in 10% cases.[6] Sureka et al. reported middle hepatic artery originated from right hepatic artery in 41.3%, left hepatic artery in 27.83% and from common hepatic artery in 4.5% patients. Origin of middle hepatic artery could not be defined in 26.3% of patients.[74] Ugurel et al. reported that arteries supplying liver segment IV originating from the right hepatic artery in 35 of the 100 cases (Ugurel et al. 2010). In an multi-detector CT study conducted by Kamel et al, the segment IV artery was reported to originate from the right hepatic artery in 62.5% of cases.[62]

Alghamdi et al. dissected a total of 29 livers and injected water and ink into the various arterial branches supplying segment IV and studied the arterial pattern supplying segment IV. In their study, the middle hepatic artery arose from the right hepatic artery in nine livers and from the left hepatic artery in a further nine instances, giving a frequency of 31% for each occurrence. The middle hepatic artery originated from the proper hepatic artery in one instance (3.4%), but was absent in nine livers

(31%). The middle hepatic artery was doubled in one instance: one arm arising from the right hepatic artery and the other from the left hepatic artery.[75]

Table 3.3 Origin of artery to segment IV reported by various authors

Author	Extrahepatic	Right hepatic artery	Left hepatic artery	Proper hepatic artery	Common hepatic artery	Not defined
Kamath.B,	35%	15%	10%	10%		
Sureka et al.		41.3%	27.83 %		4.5%	26.3%
Ugurel et al.		35%				
Kamel et al.		62.5%				
Alghamdi et al.		31%	31%	3.4%		31%

Portal vein

The portal vein begins at the level of the second lumbar vertebra and is formed by the union of the superior mesenteric and splenic veins posterior to the neck of the pancreas. The main portal vein, which carries as much as 80% of the blood supply to the liver, typically divides at the hilus into the left and right portal branches. The left portal vein is often of smaller caliber and it has horizontal and vertical portions. It courses medially to the umbilical fissure and supplies segments II, III, and IV and gives off a caudate lobe branch. The right portal vein divides into the right anterior

sector trunk, which in turn divides into segment V and segment VIII branches, and the right posterior sector trunk, which supplies segments VI and VII.[76] (Figure 3.2) The normal portal vein anatomy occurs in 90% of cases.[77]

Embryologically, the portal vein develops from the right and left vitelline veins. At 5 weeks gestational age, the right and left vitelline veins form a venous plexus around the duodenum, comprising two components ventral to the duodenum and one component dorsal to the duodenum, before terminating in the sinus venosus. By 10 weeks, selective involution of portions of this venous plexus gives rise to the adult portal vein. The main portal vein arises from the left vitelline vein and dorsal anastomoses.The right portal vein arises from the right vitelline vein, and the left portal vein from the left vitelline vein and ventral anastomoses.[78] Deviations in the development and selective involution of this venous plexus lead to portal vein variation.

The right portal vein is only 2–3 cm in length and usually divides into a right medial (anterior) sectoral division supplying segments V and VIII, and a right lateral (posterior) sectoral division supplying segments VI and VII. The medial division may give a branch to segment I.

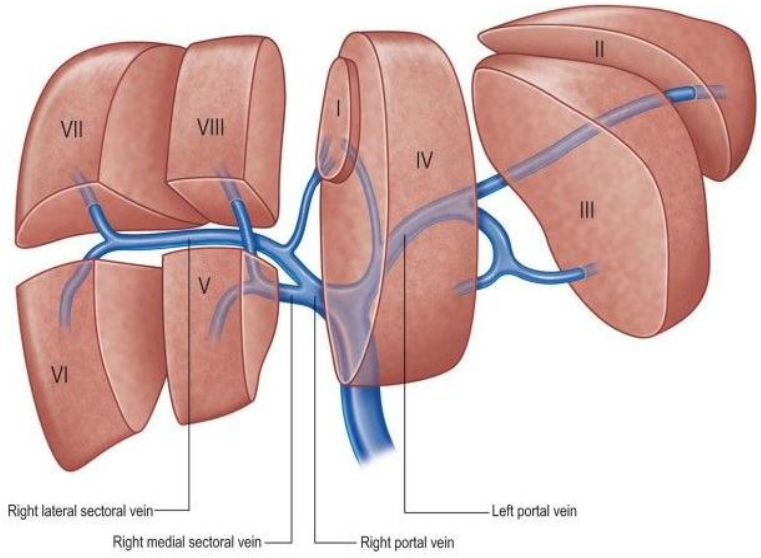


Figure 3.3. The main portal vein and its intra-hepatic branches. (Right lateral = right posterior; right medial = right anterior.). Picture is reproduced from Gray's Anatomy, 40th Edition Pg. No. 1171

Variations of portal vein branching have been reported by various authors. Nakamura classified the portal vein variations into 5 types as shown in table 3.4

Table 3.4. Variations of portal vein according to Nakamura et al. 2002

Type	Description
Type A	The usual bifurcation of main portal vein into right and left portal vein
Type B	The trifurcation pattern without the trunk of a right branch of the portal vein
Type C	A right paramedian sector branch or a right lateral sector branch bifurcates separately from the left portal vein,originated from the proximal, or extraparenchymal site
Type D	A right paramedian sector branch or a right lateral sector branch bifurcates separately from the left portal vein originated from a distal, or intraparenchymal
Type E	Branches of segment VIII and V originated separately from the left portal vein

Cheng classified portal vein variations into four types.[79] (Table 3.5)

Table 3.5. Cheng's classification of portal vein variations

Type	Description
Type I	Single left and right lobe division of the portal vein
Type II	Trifurcation of the anterior–posterior segments of the right portal vein with the left portal vein
Type III	Early segmentation of the right posterior branch of the portal vein.
Type IV	Anterior sectoral branching from the umbilical portion of the left portal vein.

The classification of branching pattern of the portal vein in current literature is as follows[80]

Type 1 - The main portal vein bifurcates into right and left portal vein trunks. The right portal vein further bifurcates into an anterior branch supplying liver segments V and VIII and a posterior branch supplying segments VI and VII.

Type 2 - The main portal vein trifurcates into a left portal vein, right anterior portal vein supplying liver segments V and VIII, and right posterior portal vein supplying liver segments VI and VII at the same craniocaudal level.

Type 3 - Early branching of the right posterior portal vein. The first branch arising from the main portal vein is the right posterior segmental branch supplying liver

segments VI and VII. Beyond this early branch, the left portal vein supplying the left hepatic lobe and the right anterior portal vein supplying liver segments V and VIII bifurcate at the same level

Type 4 - The right portal vein bifurcates into two vessels – one larger vessel supplying liver segments V, VI, and VIII and a smaller vessel supplying liver segment VII only – beyond the left portal vein origin from the main portal vein.

Type 5 - The right portal vein bifurcates into two vessels – one supplying liver segment VI only and another branch supplying liver segments V, VII, and VIII – beyond the left portal vein origin from the main portal vein.

Macdonald et al. (2005) reported in a study done using preoperative hepatic computed tomography scans and intraoperative cholangiograms from 39 consecutive living liver donors, portal venous anomalies were seen in 18%.[45]

Kishi et al. studied 287 living donor livers. They reported 91% of the portal vein branching belonged to the normal pattern Type A. 6% showed trifurcation (Type B). In their study, they did not observe Type E variation.[77]

Takeishi et al. 2015, reported that in the cohort of 407 donors, three types of portal vein were identified, 89% had a normal bifurcation pattern (type 1), 6.1% had trifurcation (type 2), 4.7% had a type 3 portal vein. In two donors, they noted a rare variation, where a posterior and a segment V portal vein branch originating from the left portal vein.[73]

Koç et al.2007, did a retrospective study done in 1384 patients (721 males, 663 females) using routine abdominal multidetector CT. Normal portal vein branching pattern was observed in 72.6% of the patients. Portal vein variants and anomalies were identified in 27.4%. The most frequent types of these variations were trifurcation in 11.1% and right posterior portal vein as the first branch of the main portal vein in 9.7%. Variation in the origin of the segmental portal vein that traversed the interlobar boundary was identified in 4%.[81]

Sureka et al. (2015) studied 967 patients using a triphasic multidetector CT abdomen scans. Normal anatomy (Type 1) was seen in 79.94%, Trifurcation (Type 2 anomaly) was seen in 6.83% of cases. Right posterior vein as first branch of main portal vein (Type 3 anomaly) was seen in 4.96% of cases. Type 4 anomaly and Type 5 anomaly was seen in 2.69% and 1.34% cases respectively. In 1.96% other types of variations were seen.

In addition to the types described, nonstandard miscellaneous variations have also been described by various authors. Covey et al. have described the following miscellaneous variations:[68]

- Trifurcation of the right portal vein into the right anterior sectoral portal trunk and into segment VI and segment VII branches.
- Division of the main portal vein into segment VI, segment VII, right anterior portal vein, and left portal vein as a “quadrification”

- Trifurcation of the right portal vein into branches supplying segment V, segment VIII and the right posterior sectoral trunk
- Segments IV and VII branches originating from the right anterior portal vein
- An accessory segment VI branch from the right portal vein in a patient with type 5 portal vein branching
- Trifurcation of the main portal vein into segment VI branch, left and right anterior sectoral branches, and segment VII branch.

Gunasekaran et al. reported a right portal vein bifurcation into separate superior and inferior branches supplying liver segments VI and VII and V and VI, respectively[80]

Koc et al reported the following miscellaneous variation:[81]

- Separate origin of segment IV portal vein branch from the main portal vein
- Quadrification
- Separate origin of the liver segments VI and VII branch from the main portal vein

Sureka et al. described the following variations:[74]

- Segment V branch arising from right posterior portal vein
- Separate origin of branch to segment VI and segment VII branch from right portal vein
- Accessory segment VI branch arising from the right anterior portal vein
- Total ramification

- Branch to segment IV being supplied by right portal vein and left portal vein
- Segment II branch directly from main portal vein bifurcation
- Segment VIII branch arising from left portal vein
- Separate origin of segment V from right portal vein
- Absence of portal vein bifurcation

Interestingly, while the right portal vein showed substantial anatomic variation, left portal vein anomalies were less frequently encountered.[80]

Radiological study

Hepatic artery and portal vein anatomy can be determined noninvasively by various radiological techniques like three-dimensional (3D) CT, multidetector CT. Schroeder et al. noted that 3D integrated images contributed to surgical simulation in a better way. Sakai et al. defined the variations of the segmental hepatic structures accurately by multi-detector CT images of the portal vein, the hepatic artery and the bile duct.[82] He reported that, comparing with conventional angiography, 3D CT angiography depicted the extra hepatic arteries and the aberrant arteries successfully and also depicted the intrahepatic segmental arteries with a high detection rate.[82]

Excellent delineation of the portal vein and its branches was achieved on CT portography, and its ability to compare the cross-sectional images with

conventional arterial portograms in patients in whom categorization of the portal vein anatomy using CT alone was difficult.[68]

Luminal casting

The technique of luminal / corrosion cast has advanced since its first application by Leonardo da Vinci using wax in 16th century where the cast of the cerebral ventricles were made. Various materials such as metal alloys, celloidin, latex gum, synthetic resins/epoxy resins, polyester resins, and silicone have been used to prepare cast of vasculature and ductal architecture.[83]

An ideal casting media/resin should be of a low viscosity and nontoxic liquid, should have the property to polymerize within a short period following injection with minimal shrinking and it should resist corrosion, cleaning, and dissection and having these properties, makes it easy to inject the resin into the blood vessels or ductal system of an organ.[83]

The modern corrosion casting methods are based upon the idea of Jan Schwamnerdan of the 17th century following the injection of wax into the blood vessels the surrounding parenchyma was dissolved by a corroding agent. Hinmann in 1923 formulated the basic principle of injecting low viscosity resins which could enter vessels of small caliber. Cellulose acetyl butyrate and epoxy resin with the addition of a hardener can also be used to prepare a corrosion cast.[83]

Murakami in 1971 initiated revolutionary advancement of corrosion casting techniques. A semipolymerized methyl methacrylate was introduced for the purpose of cast making and later the casts was observed under the Scanning electron microscope.[83]

Routinely the silicon resin/gel has also been used to produce casts of various structures. These cast are of execellent quality in terms of flexibility, clarity of details and anatomical accuracy and also provide a visual representation of the internal structures.[84]

Recently Polyurethane (diphenylmethane-4,4-diisocyanate; Souda foam) foam is found to be a suitable material to make accurate casts of vessels and viscera, and to develop a method based on its use for anatomical studies. Injection of Soudafoam is a new technique of luminal casting and the method is inexpensive, simple and requires no special equipment. The polyurethane foam does not need a catalyst. It is simply diluted with acetone, which does not cause shrinkage of the cast due to evaporation during hardening. The foam naturally expands into the cavities without high pressure of the inoculum. The polyurethane foam was tested primarily in the lungs of various animal species, but also in renal, intestinal and equine digital vessels.

The drawbacks following the used of saudafoam are, multiple injections cannot be made in the same cavity since the foam solidifies quickly; the second is the slight brittleness of the cast, due to the low elasticity of polyurethane foam.[85]

The three-dimensional structure of blood vessels, ductal system, and cavities of organ and tissue can be studied using luminal cast technique. A well-prepared cast

serves an excellent tool to have a detailed knowledge of the structures studied; as the replica of the vasculature and ductal system anatomy is retrived.[83]

More recently, expensive specific products such as dental polymers (Gordon et al. 2007) or methylmethacrylate (Casteleyn et al. 2010; Debbaut et al. 2011; Madrahimov et al. 2006; Simoens et al. 1996) have been used to produce casts. [85]

MATERIALS AND METHODS

4. MATERIALS AND METHODS

The study was conducted in the Department of Anatomy and Department of Radiology, Christian Medical College, Vellore after obtaining the ethical clearance from the Institutional Review Board. It was an observational study. In this study, the gross anatomical variations of the liver and the branching pattern of hepatic artery and portal vein were studied.

4.1 Gross anatomical variation

Seventy liver specimens available in our Department were used for the study. The liver specimens were removed during routine dissection for medical undergraduate teaching and were preserved in 10% formalin. All the livers were apparently normal and without major gross deformity. The morphological variations of the liver such as changes in size and shape, presence of pons hepatis, accessory lobes and fissures, were noted. Photographs were taken to document the variations. The results obtained were then tabulated.

4.2 Branching pattern of the hepatic artery and portal vein

Sample size determination

The sample size was calculated as 113 based on the incidence of hepatic artery variations (i.e 25%) with 8% precision and 95% confidence interval.

The formula used,

$$N = \frac{4pq}{d^2}$$

where, N is the number of samples

p is the prevalence

d is the precision.

The branching pattern of hepatic artery and portal vein was studied using two techniques:

1. Luminal casting (modified)
2. Radiological study

For luminal casting 30 liver specimens were used, 15 for hepatic artery branching pattern and 15 for portal vein branching pattern. For radiological study 100 CECT images were used for each. Thus a total sample of 115 was used for each.

4.2.1 Luminal casting

Materials used:

Sauda Foam (polymethylenepolyphenylisocyanate)

- BOSS FLEXSIL GP (Silicone Sealant)
- Acetone 100%
- I/V set tube / butterfly tube / micropipette tip
- Syringe (50/20/10cc)
- Artery clamp
- Forceps
- Scissors
- Thread
- Silicon gun

Procedure:

The liver specimens without major gross deformity was chosen. The formalin fixed liver was then washed in running water overnight. Then the liver was kept in a bath which contained the anticoagulant, sodium tri-citrate for 5-6 hrs. Again the liver was washed in running water, and also syringing water through the lumen of blood vessels in the porta hepatis.

SoudaFoam (polymethylenepolyphenylisocyanate) was used to study the branching pattern of hepatic artery. The chemical was mixed with acetone in a bowl. The hepatic artery was identified in the porta hepatis and either a canula, I/V set tube/butterfly tube or micropipette tip was inserted and then tied with thread. Then using a 50cc syringe the mixture was injected and then clamped using artery clamp. After the injection of the chemical was completed, the specimen was kept in a freezer overnight (2-5 degree celcius). After keeping the casted specimen in freezer overnight, the following day the specimen was shifted to a bowl filled with water and diluted HCl and kept for another day. On the 3rd day the specimen was taken out from the water mixed with diluted HCl.

For the portal vein, glass sealant (silicon) was used for casting the specimens. The same steps were followed which was adopted for casting structures using Souda Foam while injecting with silicon material. While doing the procedure necessary safety measures were met by using apron, facemask, goggles and gloves.

Dissection was carried out using the finger fracture technique for tracing the vascular structures. The forceps was used to tease away the liver parenchyma to expose the vessels. The trunks of the hepatic artery and portal vein were identified and their pattern of division was traced and noticed. The branching pattern was recorded by drawing the line diagram.

4.2.2 Radiological study

One hundred 3D reconstructed contrast enhanced CT (CECT) images were used for this study. These images were from patients who underwent CECT for various ailments like bladder with ureteric tumour, periampullary carcinoma, suspected carcinoma of gall bladder, carcinoma of breast for metastatic evaluation, recurrent acute pancreatitis, mass arising from the tail of pancreas, carcinoma of ovary, but devoid of any pathology in the liver. These images were from 52 males and 48 females, age ranged from 8yrs to 86yrs. CECT images were obtained at 2.5-mm-thick slices using (GE- Discovery. USA). Enhancement was achieved by intravenous bolus administration of 120 ml of a nonionic contrast medium (Iopalmidol/Iohexol;) at a speed of 3 mL/s. 3D reconstruction of the hepatic artery and portal vein was performed using AW-SERVER. The branching pattern of hepatic artery and portal vein was studied. .

The data obtained was statistically analysed with software STATA V.13.1. Fisher's exact test was done to find out whether there was any gender differences in the branching pattern of the hepatic artery and portal vein.

RESULTS

5. RESULTS

5.1. Morphological variations of the liver

Seventy livers have been studied for the morphological variations. Various gross variations were observed in the study like presence of accessory fissures, grooves on the surface of the livers, lobulations, conical shaped right lobe, notched border, underdeveloped caudate process, abnormal papillary process with fissure, fissure in the caudate lobe, bilobed caudate lobe, fissure in the quadrate lobe, quadrate lobe with tongue like projection, pons hepatis and presence of accessory lobe. The frequencies of variations in morphology of liver has been tabulated in Table 5.1.

Table 5.1. Morphological variations of the liver (n = 70)

S.No	Variations	Number	Percentage
1	Fissures		
	Fissures in right lobe	36	51.43
	FIssures in left lobe	8	11.43
	Fissures in caudate lobe	19	27.14
	Fissures in quadrate lobe	23	32.86
2	Groove in the anterior surface	8	11.43
3	Lobulations in the anterior surface	3	4.29
4	Conical shaped right lobe	13	18.57
5	Notched Border	7	10.00
6	Elongated left lobe / Beaver's lobe	9	12.86
7	Underdeveloped caudate process	3	4.29
	Hypertrophied caudate process	2	2.86
8	Abnormally upturn papillary process	1	1.43
	Enlarged papillary process	3	4.29
	Underdeveloped papillary process	1	1.43
9	Quadrate lobe with tongue like projection	5	7.14
	Bilobed quadrate lobe	5	7.14
	Pons hepatis	16	22.86
10	Accessory lobe	9	12.86

Out of the 70 livers studied fissures of various size and orientations were encountered in 57 specimens (81.4 %). In 36

specimens (51.43%), accessory fissure was present on the right lobe (Figure 5.1.1). In 8 specimens (11.43%) accessory fissure was present on the left lobe also (Figure 5.1.2). Accessory fissure were present in the caudate lobe in 27.1% and in quadrate lobe in 32.86%. There were 4 instances where the fissure was present on the right lobe along with the fissure on caudate and quadrate lobe (Figure 5.1.3). Most often the fissures were present on the visceral surface and in a few cases, deep fissures were seen on the anterosuperior surface. These fissures on the anterosuperior surface were either single (10%) (Figure 5.1.4) or multiple (4.3%) (Figure 5.1.5). In 2 livers, the superior surface was irregular due to visceral impression (Figure 5.1.6).

Other than the fissures, 13 specimens (18.57%) showed conical shaped right lobe (Figure 5.1.4). Elongated left lobe or Beaver's lobe (Netter's type 4) was observed in 9 specimens (12.86 %) (Figure 5.1.7). Netter type 2 liver was seen in one specimen (Figure 5.1.4), which is characterized by a small left lobe with deep costal impressions.

Various morphological variations were observed in caudate lobe in addition to the presence of fissure. They included underdeveloped caudate process in 4.29%, hypertrophied caudate process in 2.86% (Figure 5.1.8), l in enlarged papillary process in 4.29% (Figure 5.1.8) or underdeveloped papillary process in 1.43%. Caudate lobe was bilobed in 2 specimens (Figure 5.1.9).

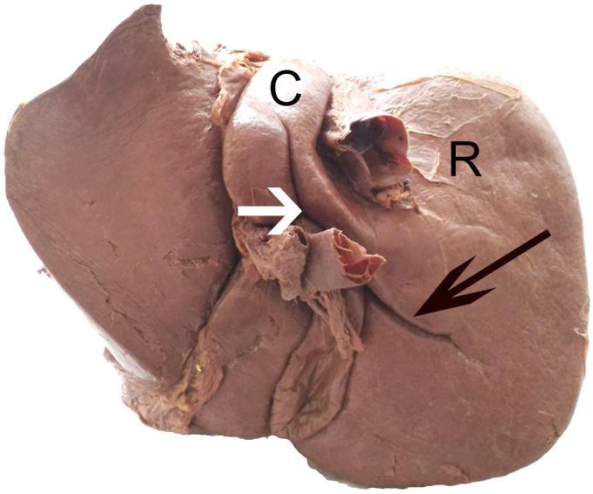


Figure 5.1.1 Black arrow indicates fissure on the right lobe of liver (R) and white arrow indicates fissure on the caudate lobe of liver (C)

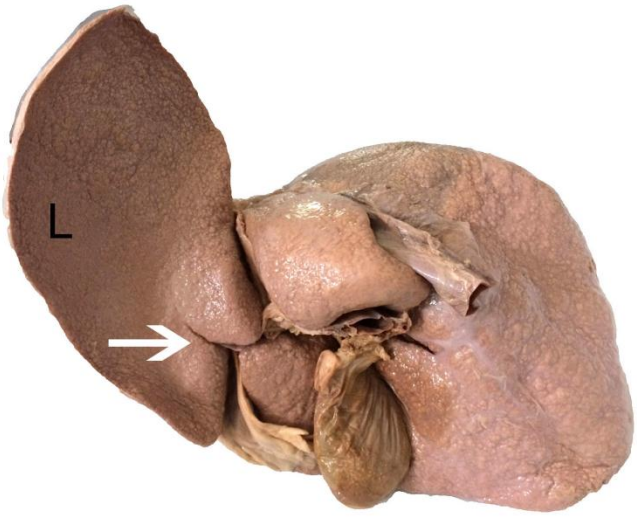


Figure 5.1.2. Arrow indicates fissure on the left lobe of the liver (L)

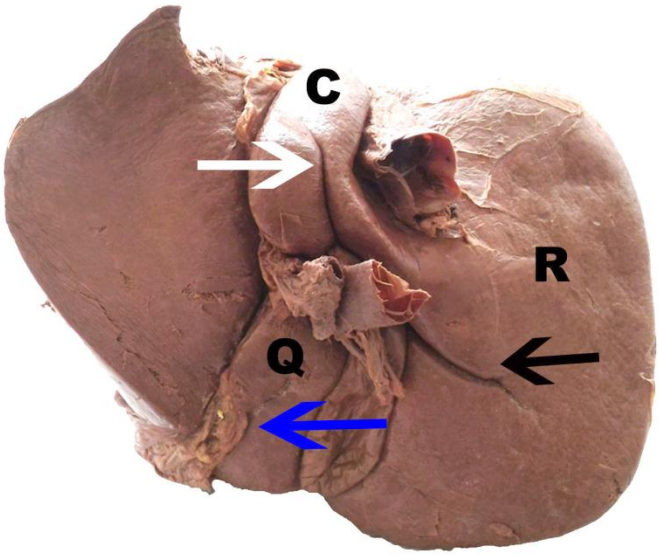


Figure 5.1.3. White arrow indicates fissure on the caudate lobe (C), black arrow on the right lobe (R) and blue arrow on the quadrate lobe (Q) of the liver

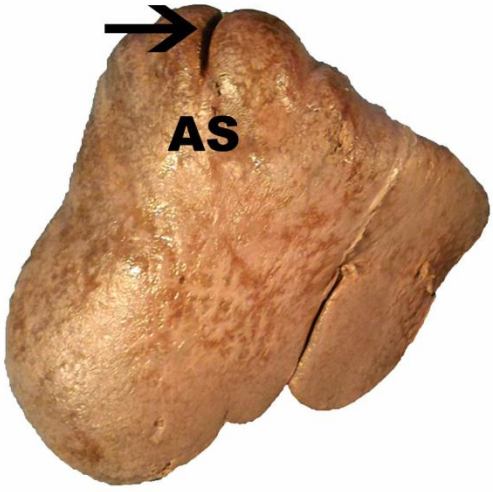


Figure 5.1.4. Black arrow shows a single deep fissure on the anterosuperior surface (AS) of the liver. Note the conical shape of the right lobe of the liver and very small left lobe (Netter's type 2)

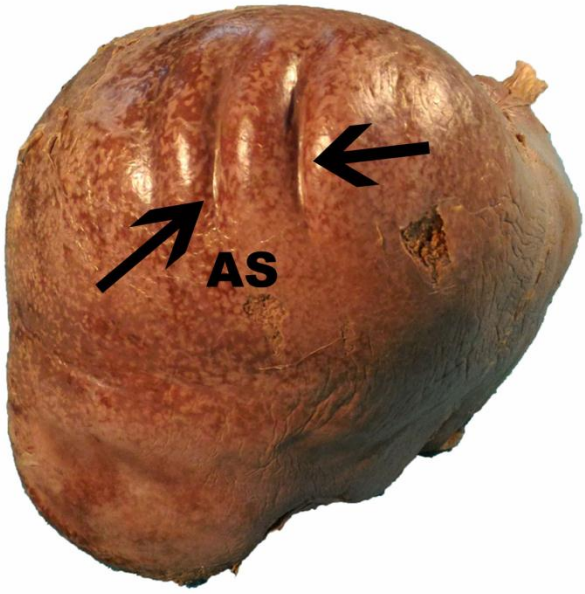


Figure 5.1.5 Arrows showing multiple fissures on the anterosuperiorsurface (AS) of the liver

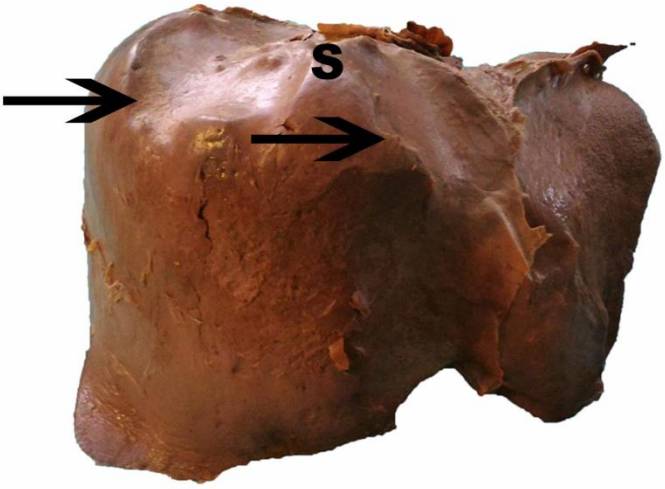


Figure 5.1.6 showing irregular superior surface (s)

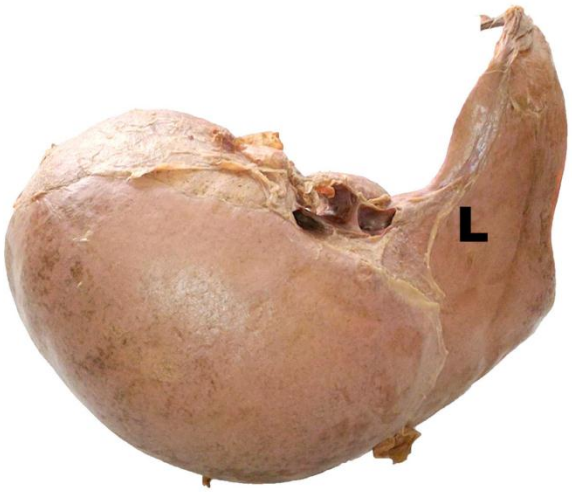


Figure 5.1.7 Showing saddle like liver with elongated left lobe of liver (L) or Beaver's lobe (Netter's type 5)

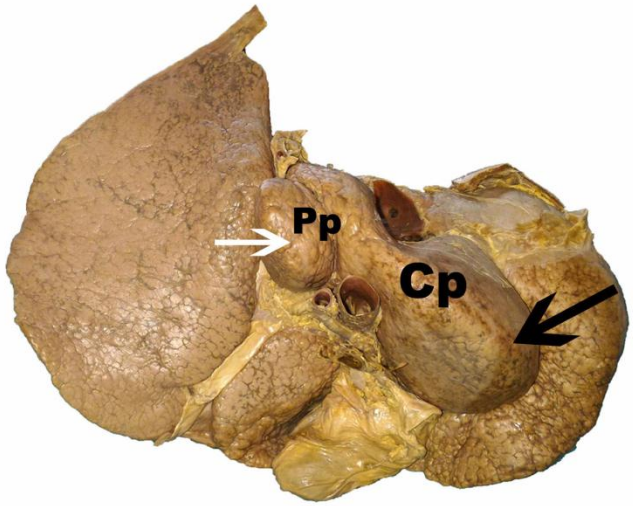


Figure 5.1.8. Black arrow indicates hypertrophied caudate process (Cp) and white arrow indicates hypertrophied papillary process (Pp)

Figure 5.1.9. Note the bilobed caudate lobe (C)

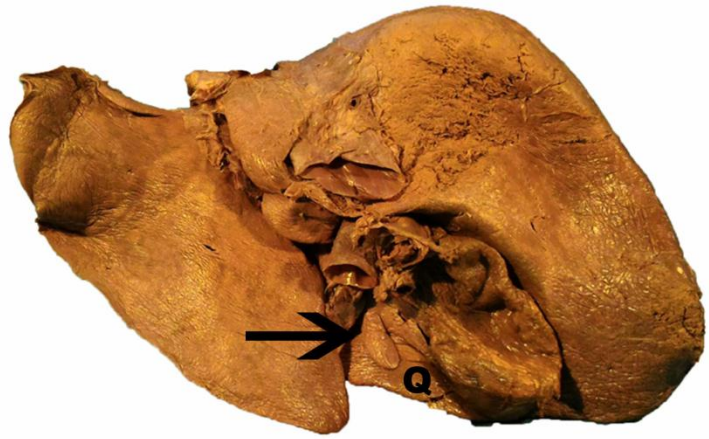


Figure 5.1.10 Black arrow indicates tongue like projection in quadrate lobe (Q)

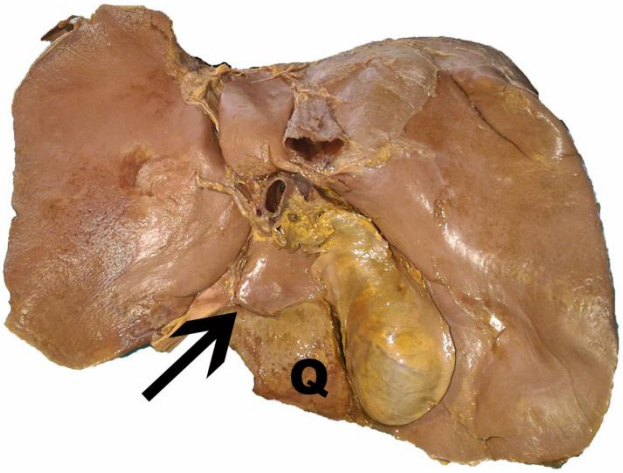


Figure 5.1.11. Black arrow indicates bilobed quadrate lobe (Q)

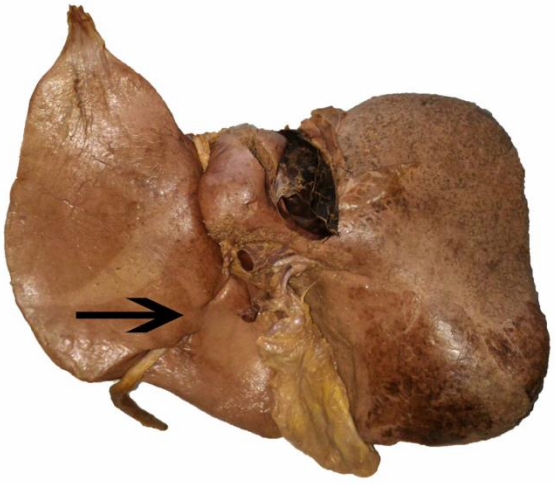


Figure 5.1.12. Black arrow indicates pons hepatis

Figure 5.1.13 Showing liver with the notch border

Figure 5.1.14. Black arrow shows the accessory lobe in the quadrate lobe of liver

Twenty three liver specimens (32.86%) showed the presence of fissure in quadrate lobe. Tongue like projection was seen in 5 (7.14%) specimens (Figure 5.1.10) and bilobed quadrate lobe 5 specimens (7.14%) (Figure 5.1.11). Pons hepatis was seen in 16 specimens (22.9 %) (Figure 5.1.12)

Notched border was encountered in 7 specimens (10 %) (Figure 5.1.13). Accessory lobe was seen in 9 specimen (12.86%) either in caudate lobe or in quadrate lobe or adjacent to these lobes (Figure 5.1.14).

5.2. Hepatic artery branching pattern

Extrahepatic branching pattern

The extra-hepatic branching pattern of the hepatic artery was studied radiologically using CECT in 100 subjects. In the current study normal anatomy was observed in 78% subjects while the remaining 22% subjects showed variations. Figure 5.2.1 shows the normal branching pattern of the hepatic artery. The common hepatic artery arose from the coeliac trunk, from which the proper hepatic artery was given off. The proper hepatic artery divided into the right and left hepatic arteries. The variations noted in this study were, common hepatic artery arising from the superior mesenteric artery in 1% (Figure 5.2.2), a replaced right hepatic artery in 13% (Figure 5.2.3) and, accessory left hepatic artery from left gastric artery in 3 cases (Figure 5.2.4) and early branching of right hepatic artery from common hepatic artery just beyond common hepatic artery origin was seen in one case. Of the variations noted, the replaced right hepatic artery had a higher incidence (Chart 1). There

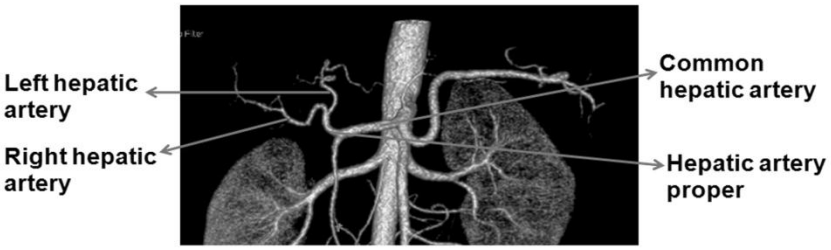


Figure 5.2.1 Common hepatic artery arising from the coeliac trunk, giving rise to gastroduodenal artery and hepatic artery proper which in turn divides into right hepatic artery and left hepatic artery

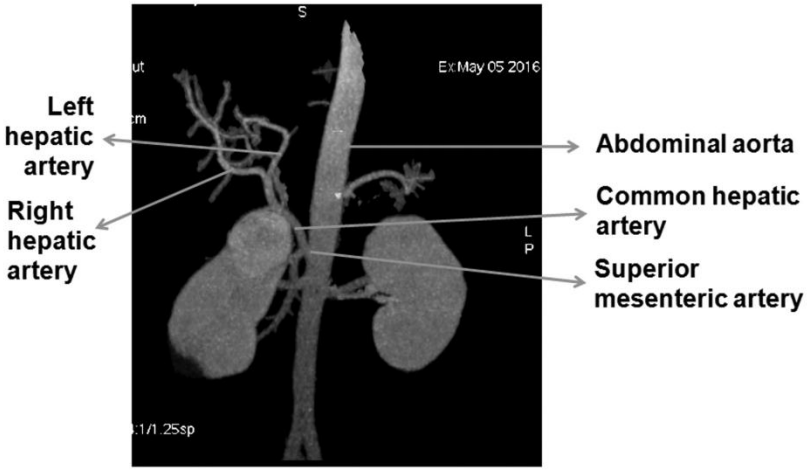


Figure 5.2.2. Common hepatic artery arising from superior mesenteric artery

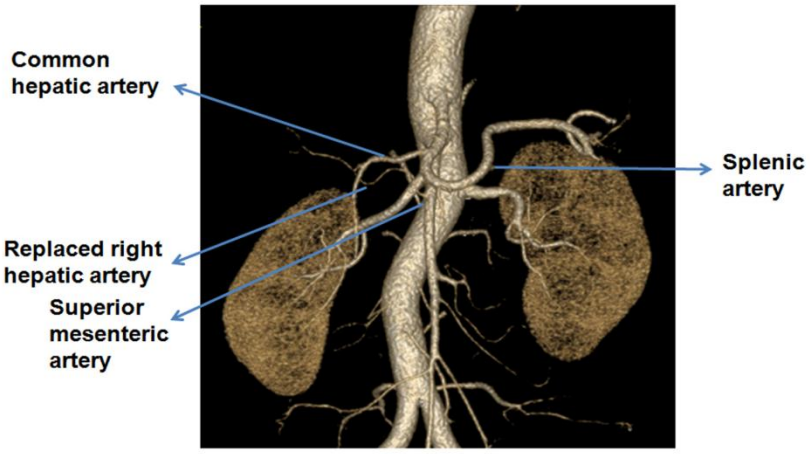


Figure 5.2.3 Replaced right hepatic artery arising from the superior mesenteric artery

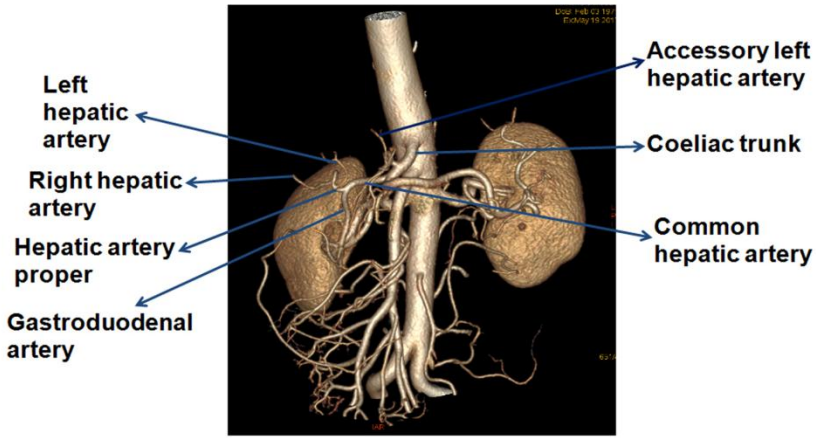
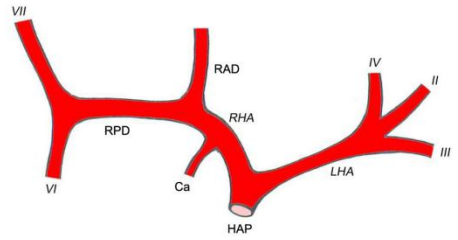


Figure 5.2.4 Common hepatic artery arising from the coeliac trunk, giving rise to gastroduodenal artery and hepatic artery proper which in turn divides into right hepatic artery and left hepatic artery

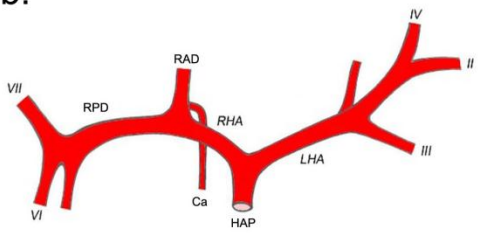
Figure 5.2.5. Intrahepatic branching pattern of hepatic artery

a.



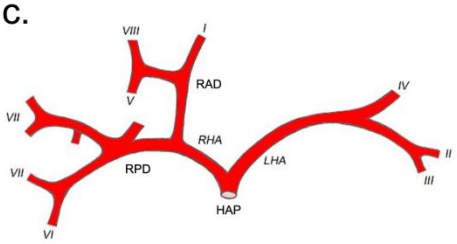
Hepatic artery proper (HAP) divides into right hepatic artery (RHA) and left hepatic artery (LHA). The RHA gives rise to cystic artery (Ca) and then divides into right anterior division (RAD) and right posterior division (RPD). The LHA supplies segments II, III, IV

b.



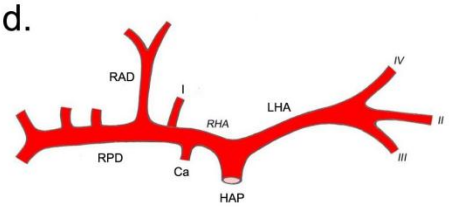
Cystic artery (Ca) arises from the right anterior divistion (RAD). HAP - hepatic artery proper; RHA - right hepatic artery; LHA - left hepatic artery; RPD - right posterior division

c.



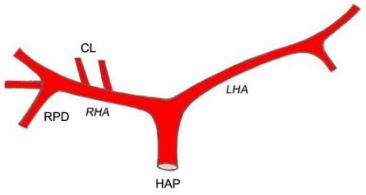
Right anterior division (RAD) gives a branch to caudate lobe (I). HAP - hepatic artery proper; RHA - right hepatic artery; LHA - left hepatic artery; RPD - right posterior division

d.



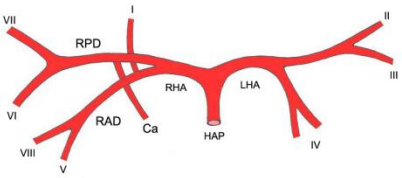
Right hepatic artery (RHA) gives rise to cystic artery (Ca) and a branch to caudate lobe (I) and then divides into right anterior division (RAD) and right posterior division (RPD). HAP - hepatic artery proper; LHA - left hepatic artery

e.



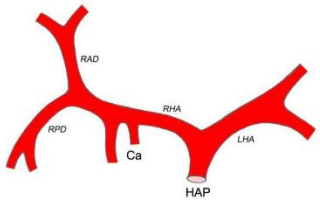
Right hepatic artery (RHA) gives off dual branches to caudate lobe (CL) and the right posterior division trifurcates. LHA - left hepatic artery

f.



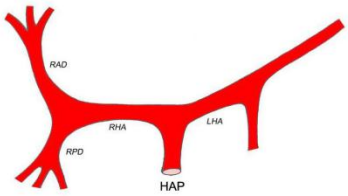
Right anterior division (RAD) gives rise to artery to caudate lobe (I) and right posterior division (RPD) gives rise to cystic artery (Ca). HAP - hepatic artery proper; RHA - right hepatic artery; LHA - left hepatic artery

g.



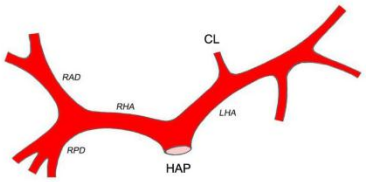
Right hepatic artery (RHA) gives rise to cystic artery (Ca). RAD - right anterior division; RPD - right posterior division; LHA - left hepatic artery

h.



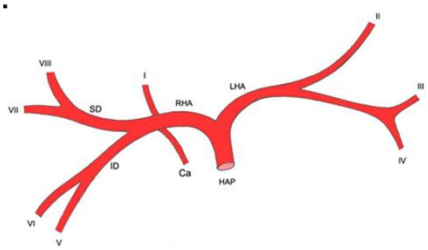
Hepatic artery proper (HAP) divides into right hepatic artery (RHA) and left hepatic artery (LHA). The RHA then divides into right anterior division (RAD) and right posterior division (RPD)

i.



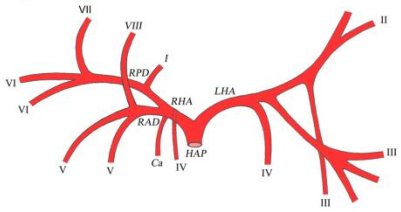
Hepatic artery proper (HAP) divides into right hepatic artery (RHA) and left hepatic artery (LHA). LHA gives a branch to caudate lobe (CL). RAD - right anterior division; RPD - right posterior division

j.



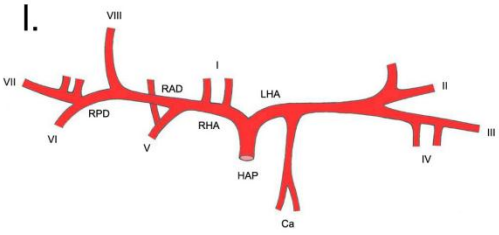
Right hepatic artery (RHA) gives rise to cystic artery (Ca) and artery to caudate lobe (I). RHA divided into superior division (SD) supplying segments VII and VIII and Inferior division (ID) supplying segments V and VI. HAP - hepatic artery proper; LHA - left hepatic artery

k.



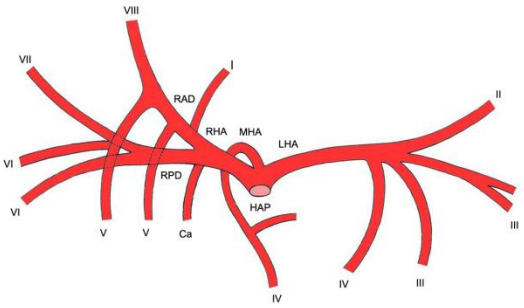
Right hepatic artery (RHA) gives a branch to segment IV and then give rise to cystic artery (Ca). Right posterior division (RPD) gives rise to artery to caudate lobe (I). LHA - left hepatic artery; RAD - right anterior divsion

l.



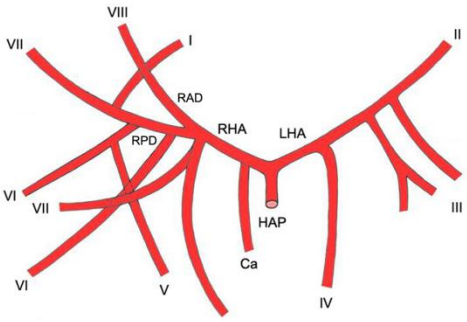
Right hepatic artery (RHA) gives a dual branch to caudate lobe (I) and then divides into right anterior division (RAD) and right posterior division (RPD). The left hepatic artery (LHA) gives rise to cystic artery (Ca)

m.



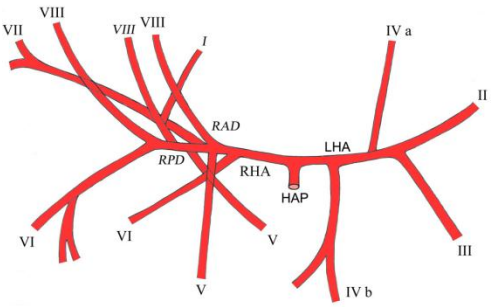
Hepatic artery proper (HAP) divides into right hepatic artery (RHA) and left hepatic artery (LHA) and middle hepatic artery (MHA). RHA gives rise to cystic artery (Ca) and then divides into right anterior division (RAD) and right posterior division (RPD). RAD gives a branch to caudate lobe (I) and there is early segmentation of RAD supplying segment V. MHA supplies segment IV

n.



Right hepatic artery (RHA) gives rise to cystic artery (Ca). Right anterior division (RAD) supplies segments IV, VII, VIII, right posterior division (RPD) supplies segments V, VI and VII. RPD gives a branch to caudate lobe (I). HAP - hepatic artery proper, LHA - left hepatic artery

o.



Early segmentation of right hepatic artery (RHA) giving a branch to segment VI. Early segmentation of right posterior division (RPD) giving branches to V, VII and VIII. Right posterior division (RPD) gives a branch to caudate lobe (I). HAP - hepatic artery proper; LHA - left hepatic artery

was no gender difference regarding the variation in the branching pattern (Table 5.2)

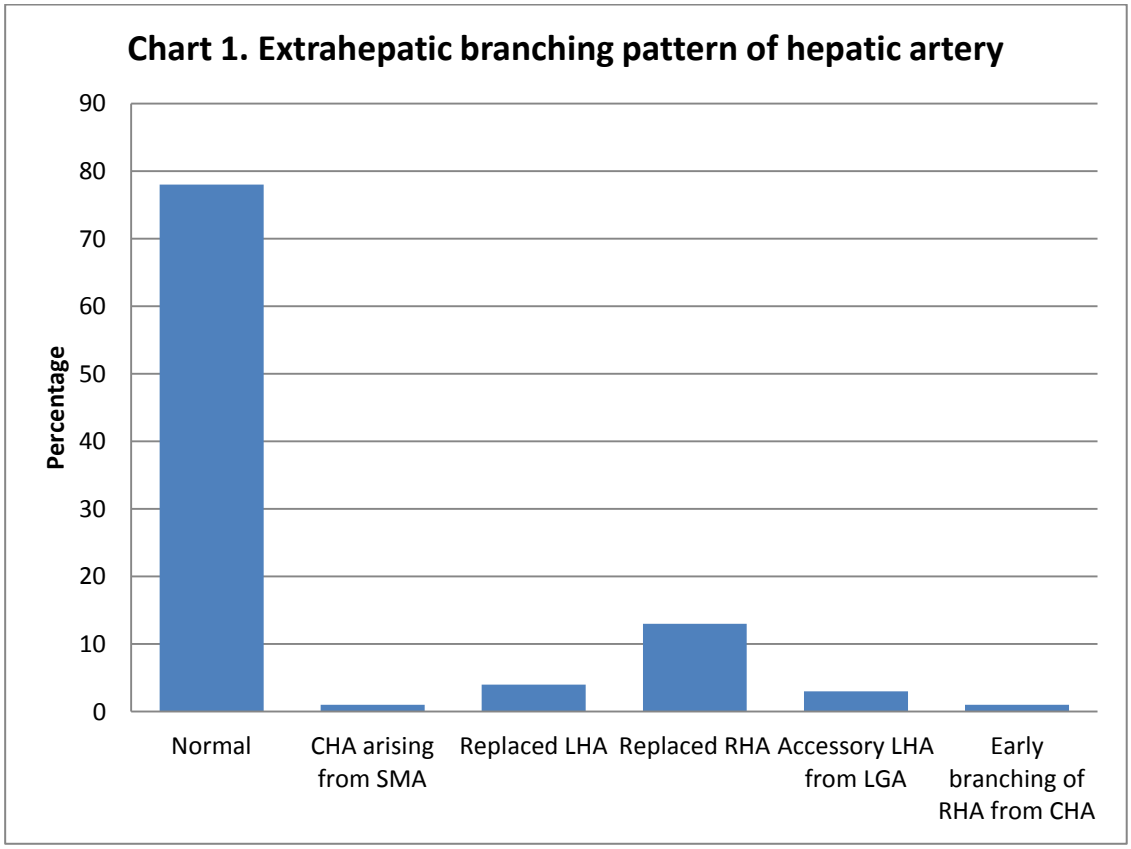


Table 5.2 Extrahepatic branching pattern of hepatic artery (n=100)

S.No	Branching pattern	Female (n=44) N (%)	Male (n=54) N %	Total in %	P value
1.	Normal	33 (75)	45(81.5%0	78	0.568
2.	CHA arising from SMA	0 (0)	1 (1.9)	1	
3.	Replaced LHA	3 (6.8)	1 (1.9)	4	
4.	Replaced RHA	6(11.4)	7 (13.0)	13	
5	Accessory LHA from LGA	2 (4.6)	1 (1.9)	3	
6	Early branching of RHA from CHA just beyond origin of CHA	1 (2.3)	0 (0)	1	

p value <0.05 is significant

CHA - Common hepatic artery; SMA - Superior mesenteric artery; LHA - Left hepatic artery; RHA - Right hepatic artery; LGA - Left gastric artery

Intrahepatic branching pattern

The intrahepatic branching pattern of the hepatic artery was studied in 15 formalin embalmed liver specimens by modified luminal cast technique using Sauda Foam. Figure 5.2.5 shows the branching pattern of the hepatic artery in 15 livers. In the current study 8 specimens (53.33%) displayed normal anatomy. The proper hepatic artery divided into right and left hepatic arteries. The right hepatic artery divided into right anterior and right posterior divisions. The left hepatic artery supplied segments II, III and IV. The cystic artery arose from the right hepatic artery and the artery to the caudate lobe arose from right hepatic artery (Figure 5.2.5.a,b,c,d,e,g,h,j, Figure 5.2.6). Table 5.3 shows the variation in the origin of cystic artery, artery to the caudate lobe and artery to the quadrate lobe.

In 3 specimens (20%), the origin of cystic artery was varied; in one specimen, it was given off from right anterior division (Figure 5.2.5.b), in another from the right posterior division (Figure 5.2.5.f) and in one specimen, from the left hepatic artery (Figure 5.2.5.l, Figure 5.2.7).

The caudate lobe received its blood supply from right hepatic artery in 14 specimens. Of which, in 3 (20%) specimens artery to caudate lobe was given off from right posterior division (Figure 5.2.5.k,n,o) and in 3 (20%) specimens from the right anterior division (Figure 5.2.5. c,f,m), and in two specimens, the right hepatic artery gave dual branches to the caudate lobe before it divided into right anterior and right posterior divisions (Figure 5.2.5.e,l, Figure 5.2.8). In one specimen the artery to caudate lobe was given

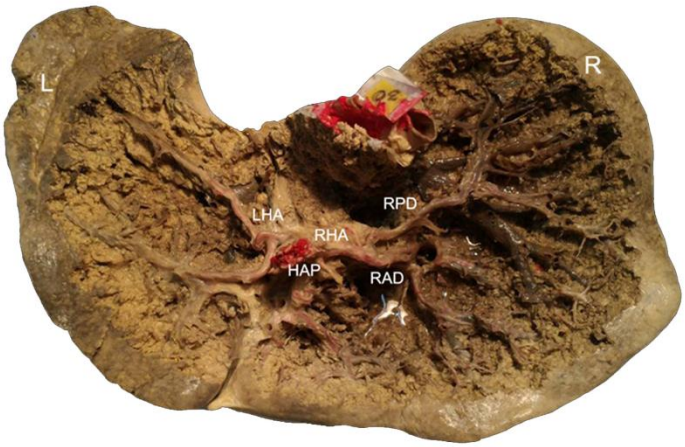


Figure 5.2.6 showing normal branching pattern of hepatic artery. Hepatic artery proper (HAP) divided into right hepatic artery (RHA) and left hepatic artery (LHA). RHA further divided into right anterior division (RAD) and right posterior division (RPD). L - left lobe of the liver; R- right lobe of the liver

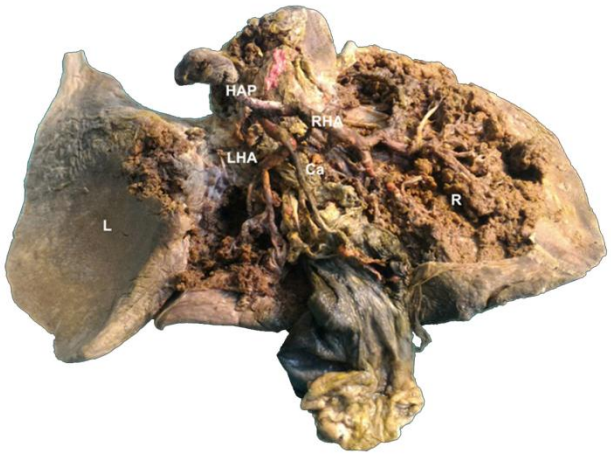


Figure 5.2.7 Showing Cystic artery arising from the left hepatic artery (LHA). HAP – hepatic artery proper; RHA – right hepatic artery; R – right lobe; L – left lobe

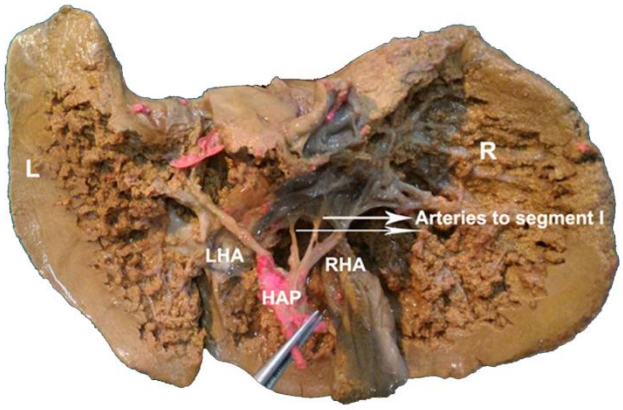


Figure 5.2.8 showing hepatic artery proper dividing into right hepatic artery (RHA) and left hepatic artery (LHA). RHA gives branches to segment I

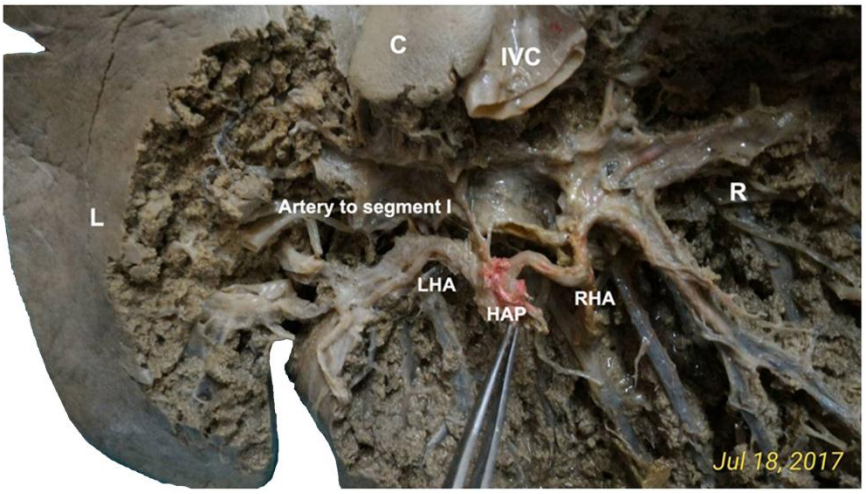


Figure 5.2.9 showing artery to segment I arising from the junction of right hepatic artery (RHA) and left hepatic artery (LHA). C – caudate lobe; IVC – inferior venacava; L – left lobe; R – right lobe

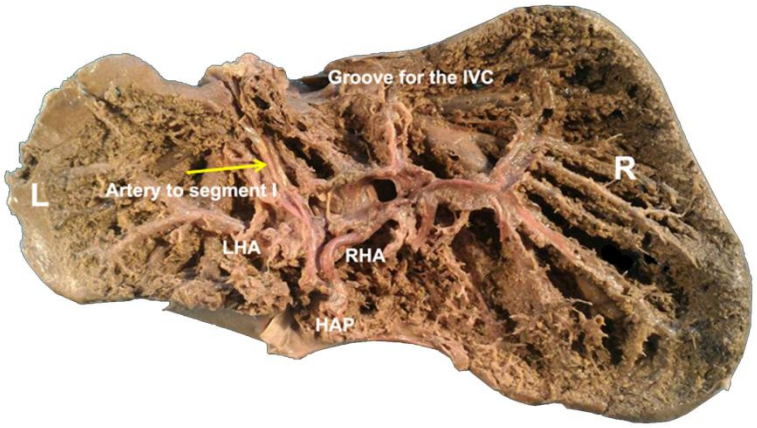


Figure 5.2.10 showing hepatic artery proper (HAP) dividing into right hepatic artery (RHA) and left hepatic artery (LHA). LHA gives rise to artery to segment I

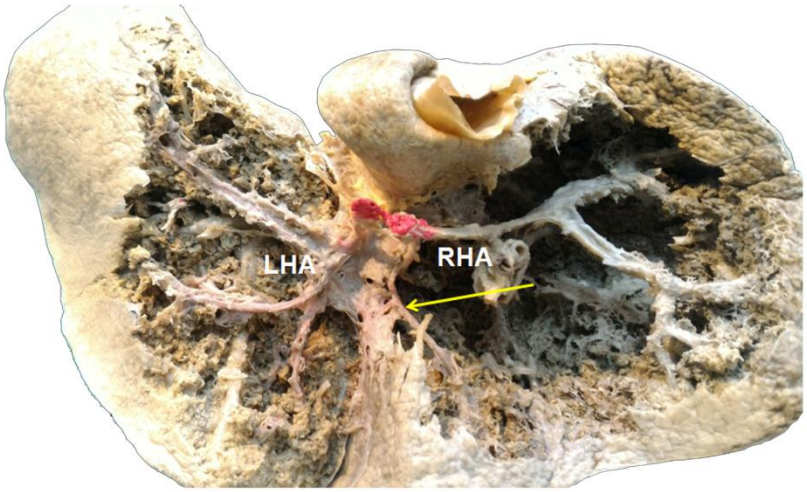


Figure 5.2.11 Arrow indicates artery to quadrate lobe arising from the right hepatic artery. LHA – left hepatic artery

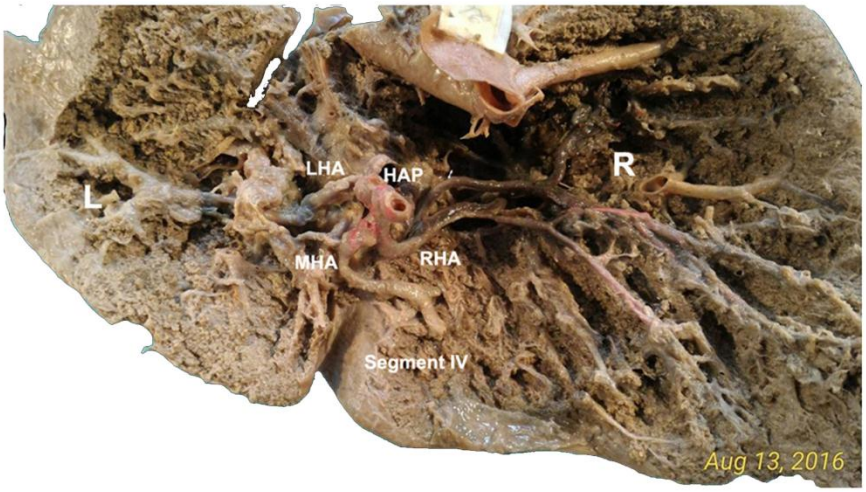


Figure 5.1.12 showing trifurcation of hepatic artery proper (HAP) into right hepatic artery (RHA), left hepatic artery (LHA) and middle hepatic artery (MHA). MHA supplies segment IV

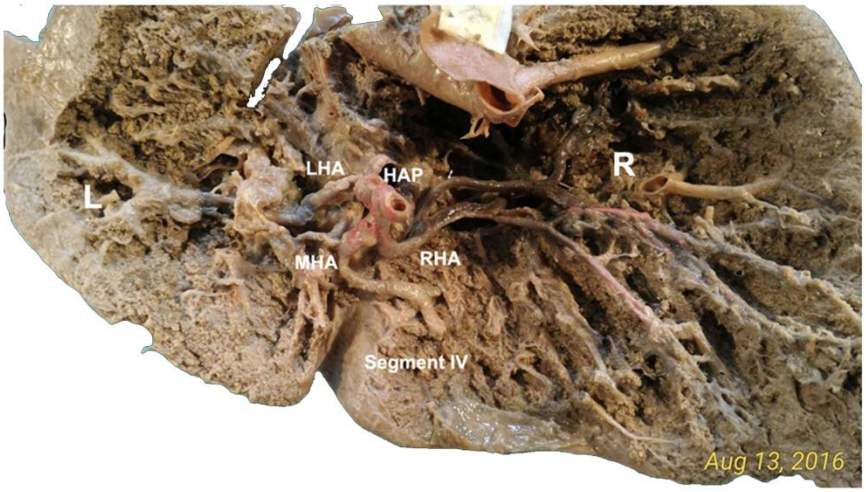


Figure 5.1.12 showing trifurcation of hepatic artery proper (HAP) into right hepatic artery (RHA), left hepatic artery (LHA) and middle hepatic artery (MHA). MHA supplies segment IV

off from the point of bifurcation of the \proper hepatic artery (Figure 5.2.9). In one specimen.(6.6 %), the artery to caudate lobe arose from the left hepatic artery (Figure 5.2.5.i, Figure 5.2.10).

Quadrate lobe received its blood supply from left hepatic artery in most of the cases. Variations in the arterial supply to the quadrate lobe was observed in 3 specimens. In one specimen (6.6 %), the right hepatic artery gave a branch to quadrate lobe (Figure 5.2.5.k, Figure 5.2.11) and in another right anterior division of right hepatic artery gave a branch to quadrate lobe (Figure 5.2.5.n). in another specimen the hepatic artery proper trifurcated into right hepatic artery, left hepatic artery and middle hepatic artery and in this case the middle hepatic artery gave a branch to the quadrate lobe (Figure 5.2.5.m, 5.2.12).

Segmental branching pattern

Segment V in addition being supplied by right anterior division, in two specimens was supplied by right posterior division (Figure 5.2.5.n,o). Segment VIII was supplied by right posterior division in three specimens (Figure 5.2.5l,n,o). In one specimen, the right hepatic artery divided into superior and inferior division. The superior division supplied segments VII and VIII and the inferior division supplied segments V and VI (Figure 5.2.5.j). In another specimen, there was early segmentation of right posterior division giving branches to segments V, VII and VIII and the branch supplying the segment VIII also gave a branch to caudate lobe and the right posterior further goes and supplies segments VI and VIII (Figure 5.2.5.o).

Segment VI was supplied by right posterior division in all 15 specimens.

In addition there was an early segmentation of the right hepatic artery which supplied segment VI. Segment VII along with quadrate lobe was supplied by right anterior division in one specimen (Figure 5.2.5.n), while in other specimens supplied by right posterior division.

Table 5.3 Variation in intrahepatic branching pattern of hepatic artery (n=15)

Description		Number	Percentage
Normal branching pattern		8	53.33
Cystic artery	Arising from right anterior division	1	6.67
	Arising from right posterior division	1	6.67
	Arising from left hepatic artery	1	6.67
Artery to caudate lobe	Arising from right anterior division	3	20
	Arising from right posterior division	3	20
	Dual arteries directly from right hepatic artery	2	13.33
	Arising from left hepatic artery	1	6.67
	Arising from the point of bifurcation	1	6.67
Artery to quadrate lobe	Arising from right hepatic artery	1	6.67
	Arising from right anterior division	1	6.67
	Middle hepatic artery arising directly from hepatic artery proper, supplying quadrate lobe	1	6.67
	Arising at bifurcation	1	6.67

In summary, the variation in branching pattern of hepatic artery:

Right hepatic artery - gave rise to cystic artery and artery to caudate lobe. In addition to it in one specimen it gives a branch to segment IV in one specimen there was early segmentation of the right hepatic artery giving a branch to segment VI.

Left hepatic artery - normally supplied segments II, III, IV. In addition, it gave rise to cystic artery in one specimen, and also gave rise to artery to caudate lobe in one specimen.

Right anterior division - supplied segments V and VIII, in addition, it gave rise to artery to caudate lobe in 3 specimens, cystic artery in one specimen, artery to segment VI in one specimen, early segmentation was seen in one specimen supplying segment IV.

Right posterior division - supplied segments VI and VII, in addition, it gave rise to cystic artery in one specimen, gave a branch to segment VIII in two specimens, in one specimen there was a branch to caudate lobe and in two specimen it gave a branch to segment V

5.3 Branching pattern of the portal vein

The branching pattern of the portal vein was studied by CECT in 100 subjects and by by modified corrosion cast technique in 15 formalin embalmed liver specimens. Table 5.4 shows the frequency of the variations of the portal vein in the radiological study. The normal anatomy of the portal vein was observed in 89% subjects while the remaining showed variant branching pattern. Figure 5.3.1 shows the normal branching pattern of the portal vein, where the main portal vein divided into right and left portal veins. The most common variation encountered was Type 2, where there was trifurcation of portal vein into right anterior portal vein, right posterior portal vein and left portal vein. This variation was seen in 5% (Figure 5.3.2). There were 4 incidences where the Type 3 pattern (separate origin of right posterior portal vein from main portal vein, then common trunk which divides into right anterior portal vein and left portal vein was observed (Figure 5.3.3a and Figure 5.3.3b). Type 5 variation (segment VI branch was first branch of the right portal vein) was observed in one case (Figure 5.3.4). In addition, in another case, branch to segment VII arose from left portal vein (Figure 5.3.5). Of the variations noted, type 2 and type 3 were more common (Chart 2). There was no gender difference in the branching pattern of the portal vein (Table 5.4).

Figure 5.3.1 showing main portal vein dividing into right portal vein and left portal vein

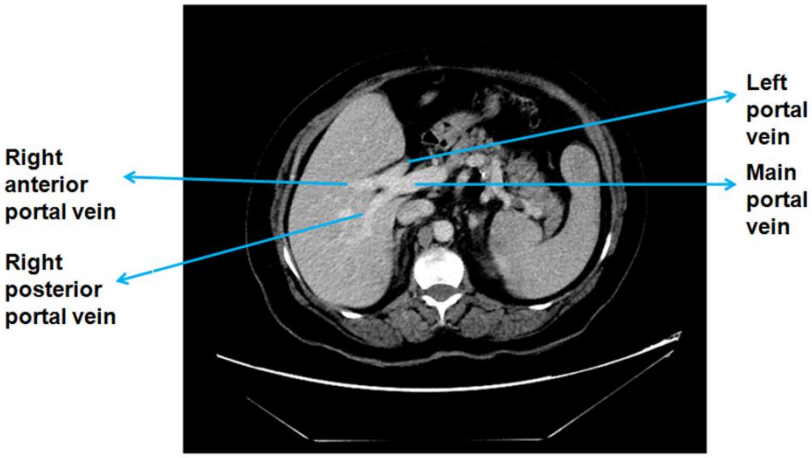


Figure 5.3.2. Main portal vein trifurcates into right anterior portal vein, right posterior portal vein and left portal vein

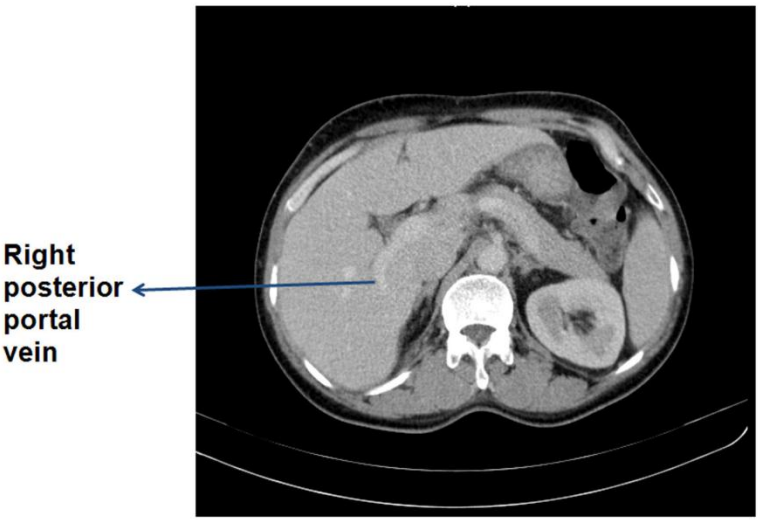


Figure 5.3.3a shows separate origin of right posterior portal vein (RPPV) from the main portal vein (MPV) first (Type 3)

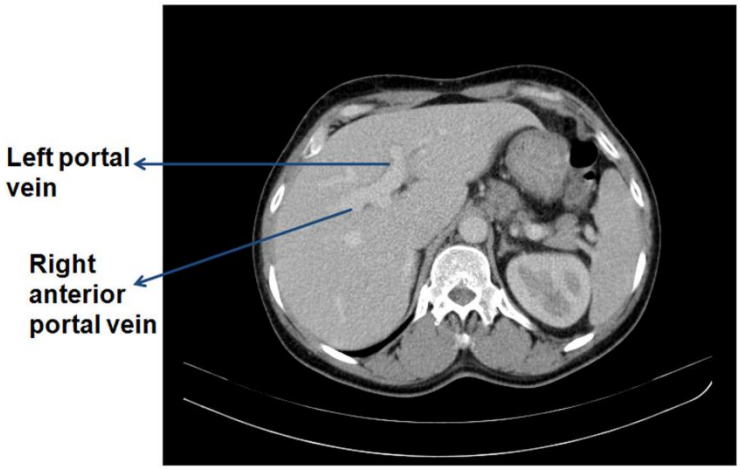


Figure 5.3.3b shows type 3 variation of the portal vein, showing right anterior portal vein (RAPV) and left portal vein (LPV)

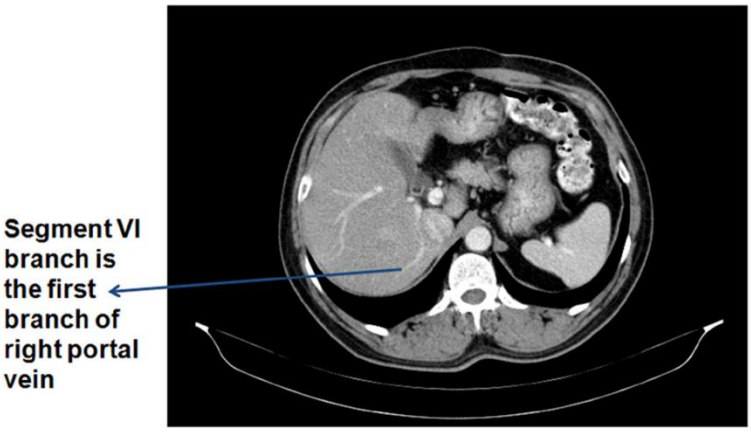


Figure 5.3.4 shows segment VI branch is 1st branch of right portal vein (RPV), showing the origin from main portal vein MPV (Type 5)

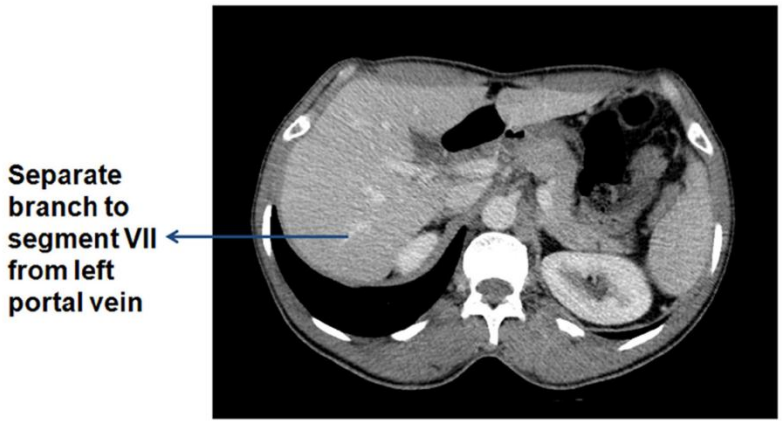


Figure 5.3.5 shows separate branch to segment VII from left portal vein (LPV)

Table 5.4 Branching pattern of portal vein by radiological study (n=100)

S.No	Branching pattern	Description	Male	Female	Total in %	P value
1	Type 1	Conventional anatomy	42	47	89	
2	Type 2	Trifurcation	3	2	5	0.757
3	Type 3	Separate origin of RPPV from MPV first, then common trunk of RAPV and LPV which divides	1	3	4	
4	Type 4	Segment VII branch is first branch of RPV	0	0	0	
5	Type 5	Segment VI branch is first branch of RPV	0	1	1	
6		Seperate branch to segment VII from LPV	0	1	1	

p value <0.05 is significant

RPPV - right posterior portal vein, MPV - main portal vein, RAPV - right anterior portal vein, RPV - right portal vein, LPV - left portal vein

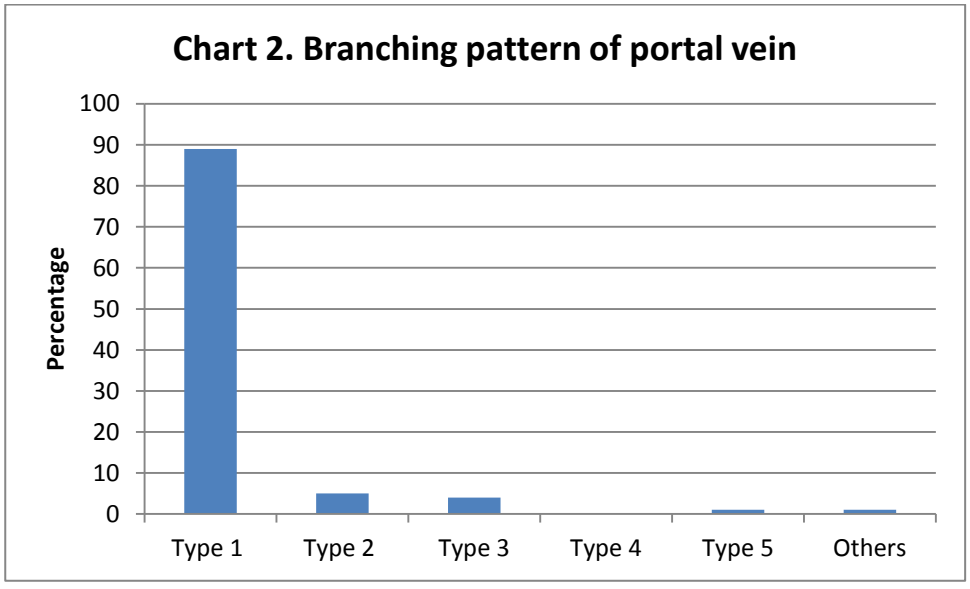


Figure 5.3.6 shows the branching pattern of the portal vein, studied by the modified luminal casting technique. Table 5.5 shows variations in its branching pattern. All the 15 specimens displayed Type I portal vein anatomy, in which the main portal vein was divided into the right and left portal veins. The right portal vein further divided into right anterior and right posterior segmental divisions. The left portal vein divided into horizontal and vertical branches (Figure 5.3.6a, Figure 5.3.7).

The portal branch to the caudate lobe arose either from the point of bifurcation of the main portal vein into right and left in 4 specimens (26.6%) (Figure 5.3.8) or from the left portal vein alone in 5 specimens (33.3%) (Figure 5.3.9) or from both the right and left in another 3 specimens (20%) (Figure 5.3.10) or from the point of bifurcation of main portal vein and left portal vein another 3 specimens (20%) (Figure 5.3.6.k,n). In 8 specimens, the caudate lobe had a single branch, either from the point of bifurcation (Figure 5.3.6.a) or from the left portal vein (Figure 5.3.6.b). In the rest, it had either dual supply or multiple veins supplying it (Figure 5.3.6.o).

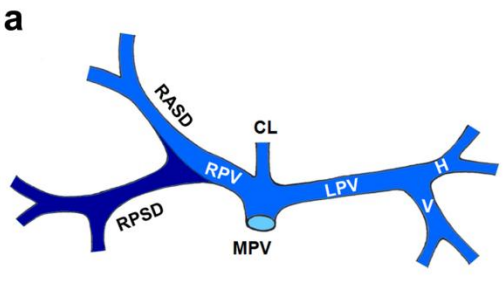
Mostly the segment VIII received the portal blood supply from the right anterior sectoral division (Figure 5.3.6.f). In 3 cases, early segmentation of right anterior sectoral division that supplied segment VIII was noted ((Figure 5.3.6.e,g,i). In addition, segment VIII also got its portal supply from right posterior sectoral division in 7 cases (Figure 5.3.11). A rare variation was seen in that, the segment VIII did not receive its supply from the right portal vein, but the vertical portion of the left portal vein in addition to its supply to the segments III and IV, gave off branches to segments V and VIII (Figure 5.3.6.k). (Figure 5.3.12).

In most of the specimens, segments VI and VII received portal blood supply from the right posterior sectoral division (Figure 5.3.6.f). In 3 specimens, segment VII received its portal blood also from right anterior sectoral division (Figure 5.3.6.e.i,k) and in one specimen, segment VI from right anterior sectoral division (Figure 5.3.6.e).

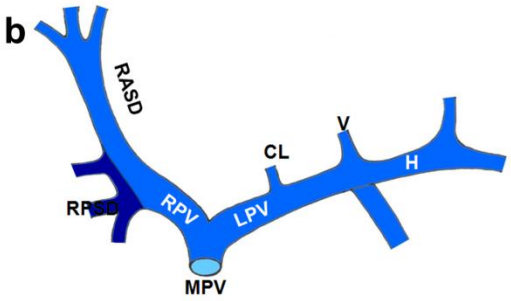
Segment V was supplied by right anterior sectoral division in most of the specimens (Figure 5.3.6.f). In 2 specimens, it also received its portal blood supply from right posterior sectoral division (Figures 5.3.6.h,o). In one case, it received its portal blood supply from left portal vein in addition to right anterior sectoral division.

In all the 15 specimens, the left portal vein supplied segments I1, III and IV. In one specimen, the segment IV, in addition to its branches from left portal vein, also received branches from right anterior sectoral division.

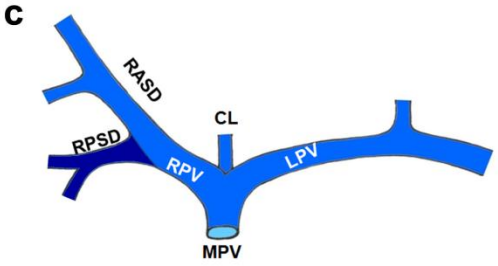
Figure 5.3.6. Branching pattern of the portal vein by luminal casting



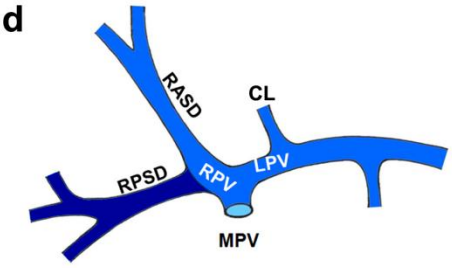
Main portal vein (MPV) divides into right portal vein (RPV) and left portal vein (LPV). RPV further divides into right anterior segmental division (RASD) and right posterior segmental division (RPSD). Caudate lobe (CL) is supplied by a branch from the point of bifurcation of MPV. H - horizontal & V – vertical portion of left portal vein



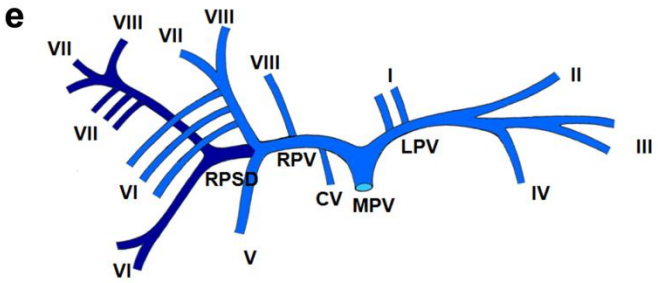
Left portal vein (LPV) gives a branch to caudate lobe (CL). MPV – main portal vein; RPV – right portal vein; RASD - right anterior segmental division; RPSD - right posterior segmental division; V & H – the vertical and horizontal portion of left portal vein.



Caudate lobe (CL) is supplies by a branch from the point of bifurcation of main portal vein (MPV). RPV - right portal vein; LPV - left portal vein; RASD - right anterior segmental division; RPSD - right posterior segmental division

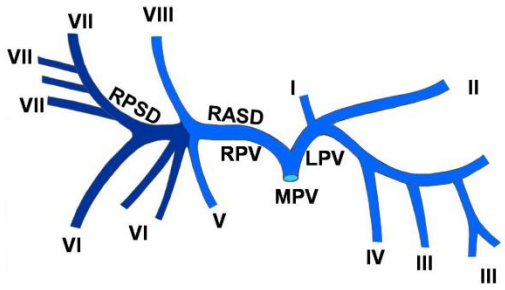


Main portal vein (MPV) divides into right portal vein (RPV) and left portal vein (LPV). RASD - right anterior segmental division; RPSD - right posterior segmental division.



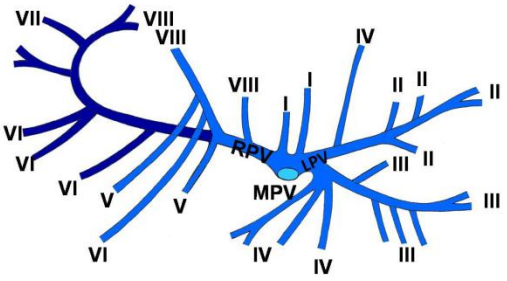
Right portal vein (RPV) gives off a cystic branch (CV). Early segmentation of RPV supplying segment VIII. Right anterior segmental division (RASD) supplies segments VI and VII. RPSD supplies segment VIII. LPV gives branches to caudate lobe (1)

f



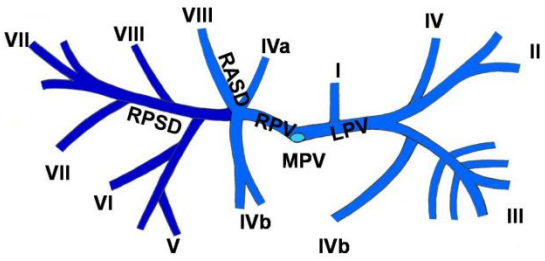
Early segmentation of right posterior segmental division (RPSD) which supplies segment VI. LPV gives a branch to caudate lobe (CL). MPV – main portal vein; RPV – right portal vein; LPV – left portal vein; RASD – right anterior segmental division.

g



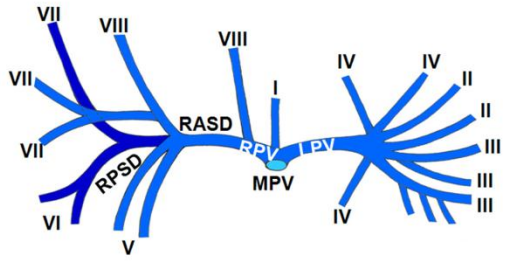
Early segmentation of right portal vein (RPV) which supplies segment VIII. Right anterior segmental division (RASD) supplies segment VI in addition to segment V and VIII and right posterior segmental division (RPSD) supplies Segment VIII in addition to segment VI and VII. Caudate lobe (I) receives branches from the point of bifurcation of main portal vein (MPV) and from the junction of MPV and LPV. LPV – left portal vein

h



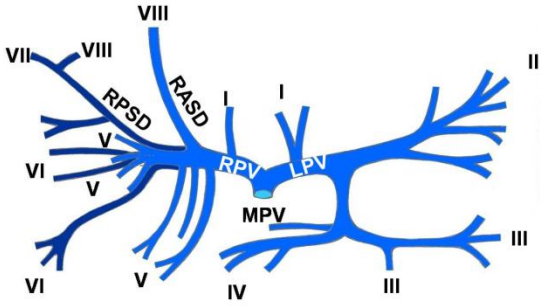
Right anterior segmental division (RASD) supplies segments IV and VIII. Right posterior segmental division (RPSD) supplies segments V,VI,VII and VIII. LPV supplies the caudate lobe (I). MPV – main portal vein; RPV – right portal vein; LPV – left portal vein.

i



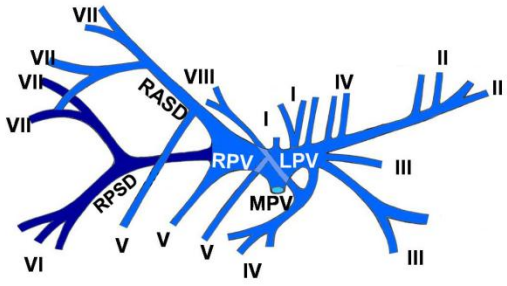
Early segmentation of right portal vein (RPV) which supplies segment VIII. Right anterior segmental division (RASD) supplies segment VII in addition to V & VIII. Caudate lobe (I) receives its branch from the point of bifurcation of the main portal vein (MPV). RPV – right portal vein; LPV – left portal vein; RPSD – right posterior segmental artery

j



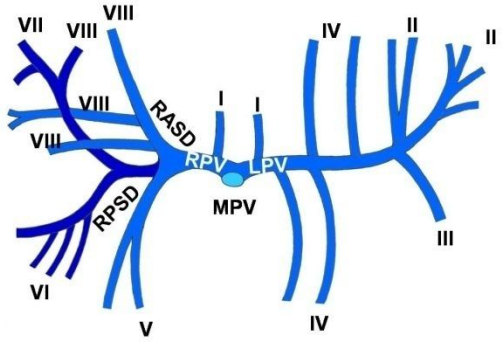
Caudate lobe (I) receives branches both from the right portal vein (RPV) and from left portal vein (LPV). Right posterior segmental division (RPSD) supplies segment VIII. MPV – main portal vein; RASD – right anterior segmental division.

k



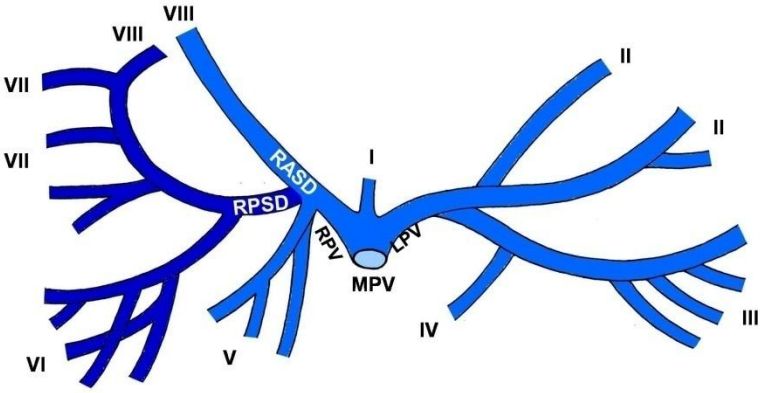
Right anterior segmental division (RASD) supplies segments V and VII. Left portal vein (LPV) supplying segments V and VIII. Caudate lobe gets multiple branches from left portal vein and also from the point of bifurcation of main portal vein (MPV). RPV – right portal vein; RPSD – right posterior segmental division.

l



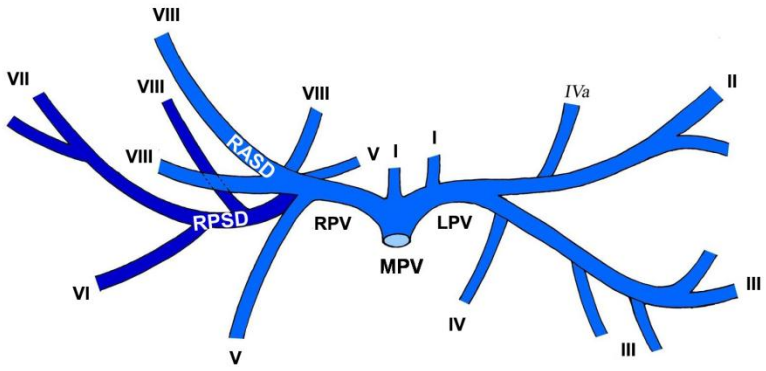
Right posterior segmental division (RPSD) supplies segment VIII. Caudate lobe (I) getting branches both from the right portal vein (RPV) and left portal vein (LPV). RASD – right anterior segmental division; MPV – main portal vein

m



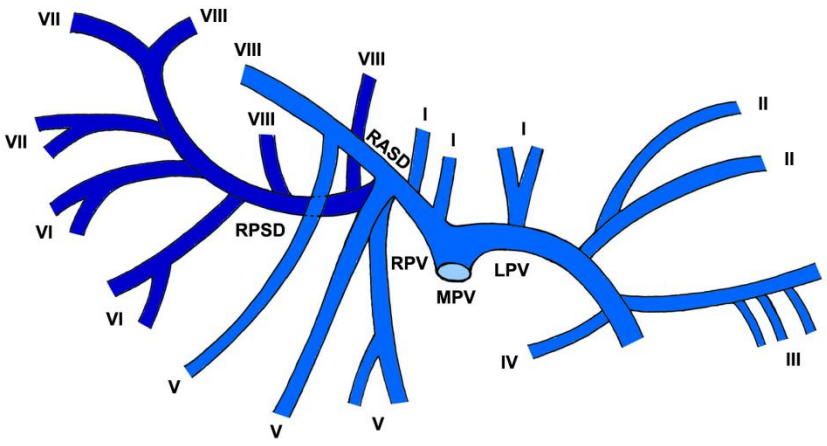
Right posterior segmental division (RPSD) supplies segment VIII. Caudate lobe (I) receives its branch from the point of bifurcation of the main portal vein (MPV). RPV – right portal vein; LPV – left portal vein; RASD – right anterior segmental division

n



Right posterior segmental division (RPSD) supplies segment VIII. Caudate lobe (I) receives branches from the bifurcation of the MPV and from the LPV. MPV – main portal vein; RPV – right portal vein; LPV – left portal vein; RASD – right anterior segmental division

o



Right posterior segmental (RPSD) supplies segment VII. Caudate lobe (I) receives branches from the right portal vein (RPV), junction of the main portal vein (MPV) and RPV, and also from the left portal vein (LPV). RASD - right anterior segmental division

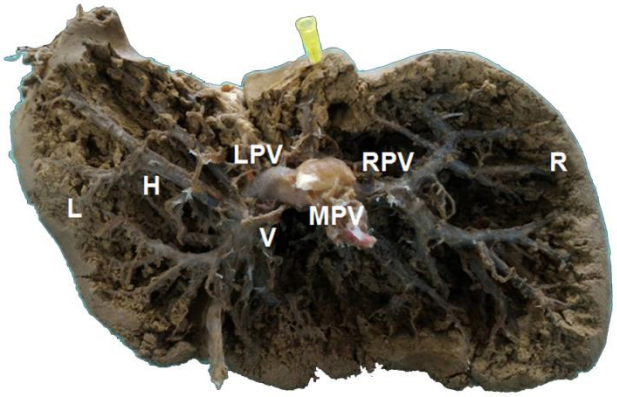


Figure 5.3.7 Main portal vein (MPV) dividing into right portal vein (RPV) and left portal vein (LPV). LPV further divides into horizontal (H) and vertical (V) portions.

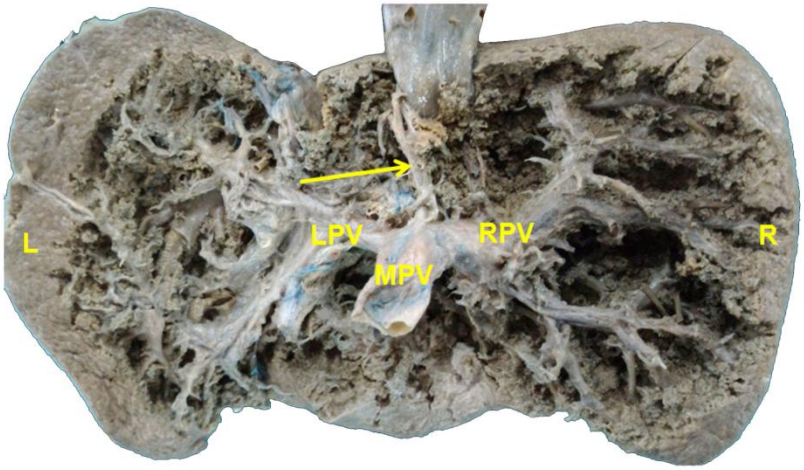


Figure 5.3.8 Arrow indicates portal branch to the caudate lobe (CL) from the point of bifurcation of main portal vein (MPV). RPV – right portal vein; LPV – left portal vein; R – right lobe; L – left lobe

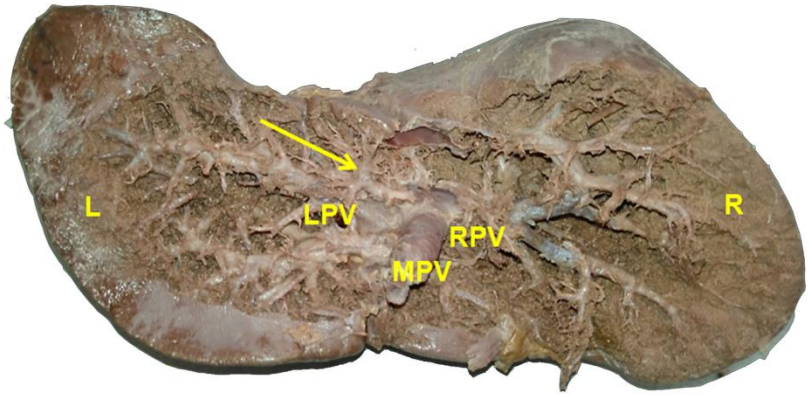


Figure 5.3.9 Arrow indicates portal branch to the caudate lobe from the left portal vein (LPV). MPV – main portal vein; RPV – right portal vein; R – right lobe of liver; L – left lobe of liver

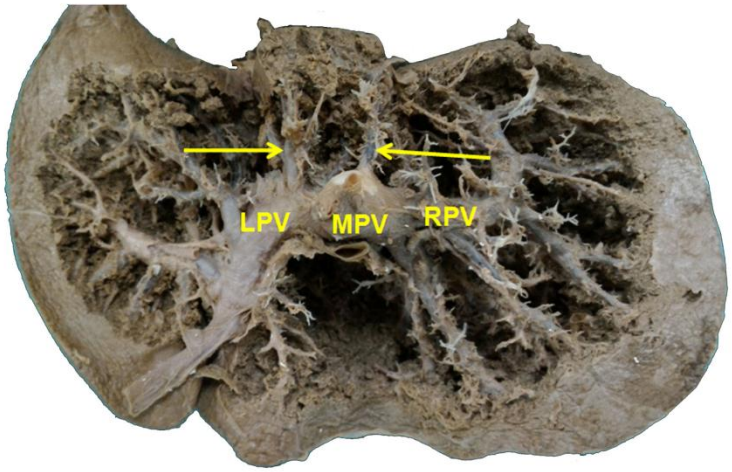


Figure 5.3.10 Arrow indicates portal branches to the caudate lobe both from the right portal vein (RPV) and from the left portal vein (LPV). MPV - main portal vein

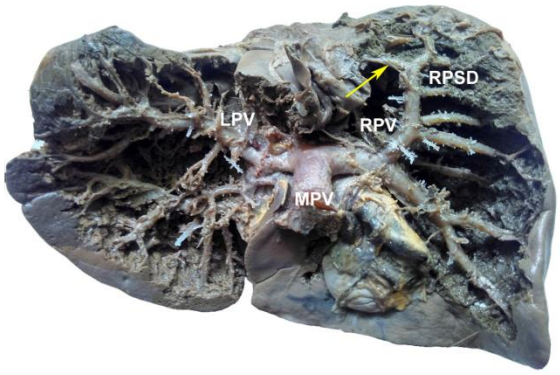


Figure 5.3.11 Arrow indicates right posterior sectoral division (RPSD) giving a branch to segment VIII. MPV - main portal vein; RPV - right portal vein; LPV - left portal vein

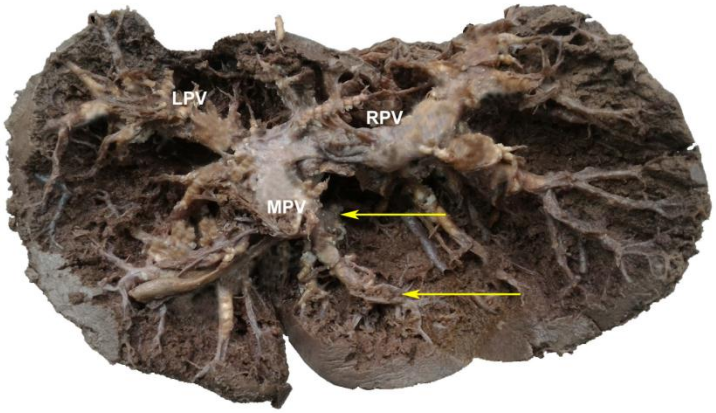


Figure 5.3.12 Arrow indicates branches to segments V and VIII from the left portal vein (LPV). MPV - main portal vein; RPV - right portal vein

Table 5.5. Variation in the branching pattern of portal vein by luminal casting (n=15)

		Number	Percentage
Conventional Type I, where the main portal vein dividing into the right and left portal vein		15	100
Branch to Caudate lobe	From left portal vein alone	4	26.33
	At the bifurcation of the main portal vein	5	33.33
	From both the right and left portal vein	3	20
	Both from left portal vein and the bifurcation of main portal vein	3	20
Right anterior sectoral division (RASD)	Early segmentation of RASD supplying segment VIII	3	20
	Supplying segment VII	3	20
	Supplying segment VI	1	6.6
	RASD superior division giving a branch to segment V	1	6.6
	Supplying IVa and IVb with absence of branch to segment V	1	6.6
	Supplying V and VII and left portal vein supplying V and VIII	1	6.6
Right posterior sectoral division (RPSD)	RPSD supplying segment VIII	7	46.6
	Early segmentation RPSD supplying segment VI	1	6.6
	RPSD supplying V and VIII and branch to segment V also supplies segment VI	1	6.6
Left vein variation		1	6.6

DISCUSSION

6. DISCUSSION

Intervention of liver by both surgeons and radiologists is ever increasing. The threat of ischemic complications following massive resection, especially in living donor hepatectomy or split liver transplantation, has been haunting surgeons for many years.[86] The knowledge of normal and variant anatomy of the liver is critical for the safe and efficacious surgical and percutaneous hepatobiliary interventions.

6.1. Morphological variations of the Liver

Morphological variations of the liver are rare and usually asymptomatic. [14] It could either be congenital or acquired. Some of the congenital defects include agenesis of the lobes, absence of segments, deformed lobes, smaller lobes, atrophy of the lobes and hypoplastic lobes.[12] Various authors have reported morphological variations of the liver. A comparision of their finding with the present study has been depicted in Table 6.1

The presence of accessory fissures in the liver has been demonstrated by various studies. The present study showed accessory fissures in the right, left, caudate and quadrate lobes of the liver in 57 specimens (81.4%). Fissures were more common on the right side (51.43%) when compared with the left (11.43%). This finding is in accordance with Sangeetha et al. who observed more fissures on the right lobe of the liver.[16] In the present study, accessory fissures were observed more on the visceral surface which is in accordance with Jurkovikj, 2016 and Saritha, 2015.[14,87]

Prominent vertical groove on anterosuperior surface were found in 6% of the liver by Joshi SD et al.,[88] 19.23% by Jurkovikj[87] and in 7.5% by Chaudari et al.[12] which is in accordance with the present study. But Macchi et al observed a higher incidence of these grooves i.e., 40% on the diaphragmatic surface.[89] Fissures on the diaphragmatic surface could be due to invagination of the musculature of diaphragm into the liver on the costal surface[14] and commonly seen in elderly patients.[12] But recent radiological and corrosion cast studies have shown that these represent portal fissures on surface. Macchi et al., suggested that the diaphragmatic sulci could be a good landmark for projection of the portal fissures and of the hepatic veins with their tributaries running through them.[89]

The accessory hepatic fissures are potential sources of diagnostic errors during imaging by ultrasound, CT or plain radiograph. On sectional imaging modalities, the accessory fissures are seen as single or multiple thin lines projecting inward from the periphery of the liver.[12] Any collection of fluid in these fissures may be mistaken for a liver cyst, intrahepatic haematoma or liver abscess. Implantation of peritoneally-disseminated tumour cells into these spaces may mimic intrahepatic focal lesions.[90] The multiple accessory fissures may mimic pathological macro nodular liver on CT.[14]

Morphological variation of right lobe:

Morphological variations of the right lobe are extremely rare. Hypoplasia is more common on the left lobe than on the right. Hypoplasia of the right lobe has been reported by Gathwala and Sen, and Shankar and Rabi.[4,20] In the present study, other than the fissures on the right lobe and conical shaped right lobe, no other anomalies were noticed.

Morphological variation of left lobe:

Enlargement of left lobe of liver has been previously reported. Enlargement of left lobe associated with agenesis or hypoplasia of right lobe has been reported earlier by Nikam and Kitture and Shankar and Rabi.[4,25] Abnormal 'L' shaped large left lobe, with the shift of quadrate lobe and fissure for ligamentum teres to right was noticed by Saritha et al.[14] On the contrary, atrophy or hypoplasia of left lobe also has been reported.[26] Singh 2013 reported a hypoplastic left lobe associated with accessory caudate lobe.[33] AC et al. reported Netter's type 2 livers in 5 out of 61 livers (8.19%).[91] In the present study only one liver was of Netter's type 2. Though eight livers had costal impressions, small left lobe was noted in only one specimen.

In the present study, elongated left lobe of liver (Beaver's lobe / Netter's type 5 variation) was noted in 9 specimens (12.86 %). Such variation has been previously reported by various authors.[12,27–29] The clinical significance of which is not known yet.

Table 6.1. Comparison between present study and other studies showing variations in morphological feature of liver

Morphological features	Joshi SD et al. in %	Muktyaz H and nema U in %	Patil S et al. in %	Nayak BS %	Chaudhari et al. %	Present study %
Accessory Fissures	30	12.1	10	1.81	12.5	81.42
Accessory Fissures on caudate lobe	-	-	-	-	3.7	27.14
Superior and Inferior Quadrate Lobe	20	-	4	-	7.5	-
Pons hepatis connecting left lobe with quadrate lobe	30	-	10	-	1.25	22.86
Absence of fissure for ligamentum teres	-	9.7	4	1.81	11.2	-
Riedel's lobe present	-	-	-	-	1.25	-
Elongated left lobe present	-	-	-	1.81	12.5	12.86
Mini accessory lobe present	-	-	2	-	3.7	12.86
Large papillary process	32	-	-	1.81	1.25	4.29

Morphological variation of caudate lobe:

The caudate lobe is considered as an independent segment according to Couinaud classification. Isolated resection of caudate lobe and resection of caudate lobe combined with major hepatecomy procedures for hepatocellular carcinoma or

hilar bile duct carcinoma has increased in number.[36] Therefore the knowledge of the morphological variations of the caudate lobe is essential for the surgeons. Morphological variation in caudate lobe was encountered in the present study in the form of underdeveloped or hypertrophied caudate process and underdeveloped, enlarged and abnormal upturn of the papillary process. Fissures were also noted in the caudate lobe in 27.14% which ended in a notch at the inferior border. In addition, accessory lobes were seen 2 specimens. Kogure et al reported the presence of the notch along the inferior border in approximately half of the patients undergoing hepatectomy and they confirmed the existence of a portal fissure between the Spiegel's lobe and the paracaval portions, and further proposed that the external notch can be used as an index to separate the Spiegel's lobe from the paracaval portion.[36] Chavan and Wabale also reported absence of papillary process. Auh et al observed that a normal-sized or small papillary process on computed tomography may be mistaken for enlarged portahepatis nodes. He also observed that when enlarged papillary process extends on to left side it can mimic pancreatic body mass.[90]

Morphological variations of the quadrate lobe:

Morphological variations seen in the quadrate lobe in the present study include presence of fissure, lingual like projection, accessory lobe and pons hepatis, the abnormal connection with the left lobe of the liver thereby obliterating the fissure of ligamentum teres. Absence of quadrate lobe has been reported by various authors. Muktyaz and Nema found absence of the quadrate lobe in one (2.4%) liver out of 41 livers studied.[39] A complete absence of the quadrate lobe with the absence of fissure

for ligamentum teres was observed by Pujari and Deodhare.[92] Absent quadrate lobe has been also reported by other investigators.[34,16,93] A very narrow, buried or absent quadrate lobe may create confusion in the mind of the radiologist, as the fissure for ligamentum teres in such cases would be very near to the left margin of the gall bladder fossa.[94] Sangeetha et al. concluded that the absent quadrate lobe, which in all probabilities could be congenital.[16] However, the current study did not show any absence of quadrate lobe.

Another variation noted in this study was the presence of pons hepatis. In cases of the pons hepatis, bridging the fissure for ligamentum teres, normal visualisation of the fissure would not be possible and dimensions of the right and the left lobes may be mistaken.[11] In the present study pons hepatis was noted in 22.86 which is in accordance with Khedekar and Hattangdi who reported in 14% but contradictory to the one reported by the Saritha et al. who encountered the presence of pons hepatis only in 4%.

Accessory lobe

Accessory lobe of liver is one of the most common morphological variations in the liver. It is due to the excessive formation of the liver tissue and is usually asymptomatic.[12] When the liver parenchyma is in communication with main liver, it is known as an accessory lobe and without communication is known as ectopic liver.[95] Embryologically accessory lobes are formed by the displacement of the primitive rudiment of the organ, or by persistence of the mesodermal septa during proliferation,

which occurs due to defective formation of the caudal foregut and hepatic bud in the third month of the intrauterine life.[12] Reidel's lobe is the most commonly occurring variation of the reported accessory lobes.[96] Sato S et al., reported 0.7% accessory lobe and ectopic lobe of liver in 1800 laparoscopies. Chaudhari et al. reported 3.7% mini accessory lobes. A mini accessory lobe was reported by Satheesha et al., at the posterior part of fissure for ligamentum teres.[97] A small accessory lobe connected to the tuber omentale by mesentery containing portal and biliary elements was reported by Jurkovikj.[87] Accessory lobes are most commonly found on the under surface of the liver.[12] One of the complications of accessory liver lobe is torsion especially in pedunculated form which requires emergency surgical intervention. In addition, they may be mistaken for lymph node or may be accidently removed during surgery which would result in excessive bleeding in abdomen due to damage to liver lobe or vascular pedicle.[12] In the present study, accessory lobes were seen in the undersurface of liver in 9 specimens (12.86%), mainly in quadrate lobe of liver. They were sessile. Reidel's lobe was absent in the 70 liver specimens studied.

6.2 Hepatic artery

The right and left hepatic arteries arise from the proper hepatic artery but it can also arise from either from common hepatic, superior mesenteric or left gastric arteries. The normal hepatic arterial anatomy occurs in approximately 50–80% of cases.[63] The arterial patterns are of importance in planning and performance of all surgical procedures like laparoscopic cholecystectomy, LDLT and radiological procedures in the upper abdomen. The anatomical variations contribute to misinterpretation and leads to major postoperative complications.(Hiatt JR et al, 1994)

Cystic artery

The cystic artery is a branch of the right hepatic artery. It has been previously reported that the cystic artery could arise either from proper hepatic artery, common hepatic artery.[48], gastroduodenal trunk, superior pancreaticoduodenal artery and superior mesenteric artery.[49] right gastric artery and celiac trunk.[51] Williams et al and Balija have reported cystic artery arising from left hepatic artery. In the present study, of the 15 livers dissected, in 6.66%, the cystic artery arose from the left hepatic artery. In two other specimens, it arose either from the right anterior division or right posterior division of the right hepatic artery. Knowledge about this variant origin is essential as during surgeries, cystic artery is looked for in the Calot's triangle.

Hepatic artery variations

Aberrant hepatic artery

Replaced right hepatic artery usually arises from superior mesenteric artery and has been classified as Type III as per Michel's and Hiatt's classification. According to Michel, it is the most common type of hepatic artery variations.[55]

This variation has also been reported by various authors. Lin and Chaikof reported in 19% of cases, Jones and Hardy in 19% and Chaib et al. in 25%, Sureka et al. in 15.16%.[65,98–100] Stauffer et al reported aberrant right hepatic artery in 16.2% in 191 patients. In the present radiological study, the replaced right hepatic artery was noted in 13%. Anomalies in the blood supply to the right hepatic lobe are especially relevant during pancreaticoduodenectomy and their recognition serves to protect the blood supply to the liver and bile ducts.[101]

Replaced left hepatic artery usually arises from left gastric artery and has been classified as Type II as per Michel's and Hiatt's classification. This variation has been reported by various authors like Lin and Chaikof in 25%, Chaib et al. in 3.3%, Sureka et al. in 10.8%, Yang et al. in 6.42%.[65,98,100,102] In the present study replaced left hepatic artery was observed in 4% of the population. Knowledge about the replaced left hepatic artery is vital, as there is an increased risk for inadvertent ligation of this artery during gastrectomy or hiatal hernia repair because of its proximity to the left gastric artery.[100]

In the present study, replaced right hepatic artery was more frequent than the replaced left hepatic artery which is in accordance to Michel et al. In contrast to this, Lopez-Andujar et al reported more number of replaced left hepatic artery than the right hepatic artery.[64]

In the present study, accessory left hepatic artery arising from left gastric artery was encountered in 3%, which is in accordance to Lopez-Andujar et al.who reported in 3.8%.[64]. In addition, in the present radiological study, early branching of right hepatic artery was observed in 1% of cases which is in accordance with Sureka et al. who reported in 0.83% of the 575 patients studied.

The replaced common hepatic artery arises from the superior mesenteric artery by a common trunk referred to as the hepatomesenteric trunk and has been classified as type 9 by Michels. The incidence of such an anomaly has been reported in literature to range from 0.4% to 4.5%. In the present radiological study, this anomaly was reported in 1% which is in accordance with Noussios et al 2017, who reported this variation in 1.2%.

Artery to Caudate lobe

Normally the caudate lobe or segment I is supplied by the right anterior division of the right hepatic artery.[1] Furuta et al. 2009 observed that the caudate lobe is supplied by multiple small branches arising from both the left and right hepatic artery. Artery to caudate lobe arising from the right hepatic artery mainly supplies the lateral portion of the paracaval portion and the papillary process and the artery arising from the left hepatic artery mainly supplies the caudate process and Spiegel lobe.[103] According to Miyayama et al. 2010, hepatocellular carcinoma located in the Spiegel lobe is usually supplied by the arteries derived from the right and/or left hepatic artery and in the paracaval portion is mainly supplied by the caudate artery derived from the right hepatic artery, and with low frequency by the caudate artery derived

from the left hepatic artery. Hepatocellular carcinoma in the caudate process is usually supplied by the caudate artery derived from the right hepatic artery.[104]

Yan et al. reported the artery to caudate lobe arising from the gastroduodenal trunk, where the common hepatic artery was absent. Suganthy et al. reported in a case which had multiple vascular variations of splanchnic branches of abdominal aorta, the caudate lobe was supplied by both accessory and replaced right hepatic artery. In the present study, using modified luminal casting technique revealed that the caudate lobe received direct branches from the right hepatic artery in most of the cases. In 3 specimens, the artery to caudate lobe was given off by right anterior division and another three specimens by right posterior division. In one specimen, it received arterial supply from left hepatic artery.

Miyamama et al. 1990 evaluated 106 cases using stereo magnification angiograms and found that in 15 cases, caudate lobe received two arteries. In most of the cases, both the arteries arose from the right hepatic artery and in few cases, each one from right and left hepatic arteries.[105] In the present study, dual arteries supplying the caudate lobe were seen in two cases and in both, they were arising from the right hepatic artery.

Knowledge regarding the vascular anatomy to the caudate lobe is essential to perform effective transcatheter arterial chemoembolization for hepatocellular carcinoma of caudate lobe.[104]

Artery to Quadrate lobe

The artery to the quadrate lobe/segment IV has been called as middle hepatic artery or segment IV artery. The origin of the middle hepatic showed a high degree of

variability. Identifying this artery and its pattern is important when planning and performing hepatic resection. Accidental damage to this artery can cause a number of complications such as hepatic artery thrombosis, ischemic cholangiopathy, or a decrease in the size of the left hepatic lobe. [106,107]

Controversy exists in the literature regarding the frequency of origin of middle hepatic artery. The artery to segment IV may arise either from right hepatic artery or from left hepatic artery.[54,86] or directly from hepatic artery proper.[6] Ghosh (2014) reported that the middle hepatic artery arises more often from the right hepatic artery (52.8%) than from the left hepatic artery (47.2%).[54] Wang et al. reported that the middle hepatic artery arising from the right hepatic artery in 58.3% and from the left hepatic artery in 36.9% which is similar to Ghosh.[108] Kamel et al. reported that the artery supplying the segment IV arose from the right hepatic in 62.5% patients.[62] Jin et al. had reported that the artery to segment IV was arising from the right hepatic artery in 53.2% liver specimen, and from the left hepatic artery in 32.3% cases.[86] Sureka et al reported that the middle hepatic artery arising from right hepatic artery in 41.3% patients and from left hepatic artery in 27.83%.[65]

In contrary, Onishi et al. had reported that middle hepatic artery was arising predominantly from the left hepatic artery (61.5%) than from the right hepatic artery.[109] Similarly, Kishi et al. observed that middle hepatic artery was arising from the left hepatic artery in 62.5% cases and from the right hepatic artery in 37.5% of the cases. Yoshimura et al. also reported more number of middle hepatic artery arising from left hepatic artery.[110] Futara et al. noted that the middle hepatic artery was present in 47.3% of cases and was arising in equal proportion from the left hepatic

artery (20%) and right hepattic arery (20%).[111] Wang et al. observed that in livers that had a replaced left hepatic artery, the middle hepatic artery originated from the right hepatic artery and in livers that had a replaced right hepatic artery, it originated from the left hepatic artery.[108] Yan et al reported an artery that arising from gastroduodenal artery supplying the quadrate lobe.[67] Alghamdi et al reported that the middle hepatic artery originated from the right hepatic artery and the left hepatic artery with the same frequency of 31%.[106] In the present study, the artery to segment IV arose mainly from the left hepatic artery (80%). In one specimen, the middle hepatic artery arose directly from the hepatic artery proper, another directly from the right hepatic artery and another from right anterior segmental artery.

Knowledge regarding the arterial supply to the quadrate lobe is very essential for minimising the postoperative complications. Saxena et al. reported that the quadrate lobe belongs functionally to the left lobe of the liver, hence during right lobe LDLT, preservation of the left hepatic artery and the middle hepatic artery is critical for adequate blood supply to the remaining left lobe in the donor.[112] In LDLT, injuries to the middle hepatic artery, which supplies the segment IV, may lead to a reduction in the functional volume of the left hepatic lobe and a decrease in the blood supply to bile ducts of this lobe. Complications of such arterial injuries, which may be severe, include insufficient hepatic volume, ischemic cholangiopathy, and hepatic artery thrombosis in the right lobe donor or the left lobe recipient.[112,113]

There is not much literature available regarding the intrahepatic branching pattern of the hepatic artery. In the present study other than the variation noted regarding the arterial supply to caudate lobe and quadrate lobe, variations were noted in the segmental branching of the right lobe of the liver. There was no variation in artery to segment VI. In all cases it was supplied by right posterior division. Yet in one specimen, in addition to the right posterior division segment VI was supplied by direct branch from right hepatic artery. In one specimen segment VII received its blood supply from right anterior division. Segments V and VIII were receiving its blood supply from right posterior division in a few cases. There was no variation in blood supply to the left lobe of the liver. This should be borne in mind while doing LDLT. Guler et al. mentioned that in LDLT for the treatment of end-stage liver disease, right lobe is generally preferred as it provides a larger size liver graft. Though left lobe has been used for LDLT, it is not preferred because of 'small for size' syndrome and graft loss.[114] With the right lobe being used for LDLT, there is an associated higher incidence of variations in the distribution of the vascular and biliary system as compared with the left lobes. [8] One of the most devastating complication in LDLT is the thrombosis of hepatic artery.[114] Therefore knowledge about the variation in intrahepatic branching pattern is essential for the surgeons to avoid complication.

6.3 Portal vein

Preoperative assessment of the portal vein system is essential for safe hepatectomy.[9,77] The incidence of variant portal vein anatomy in the liver and the

implications for surgical and radiologic interventions are increasingly obvious.[115] With the growing popularity of complex hepatobiliary surgical and percutaneous procedures, including trisegmentectomy, portal vein embolization, the detection and recognition of portal vein variants are increasingly relevant. In LDLT, careful manipulation of the vasculobiliary system is critical to avoid causing injury to portal vein in the residual liver and/or the graft.[10],[45],[116],[47] In addition, prompt identification of anatomical anomalies can help the surgeon to determine whether cancer located at the porta hepatis is operable or not.[117]

In addition to LDLT, TIPS have been employed for the treatment of portal hypertension. For TIPS, the right portal vein is commonly accessed. TIPS involves transhepatic puncture of the right portal vein branch from the right hepatic vein.[80] Therefore thorough knowledge of the variation of intrahepatic course of portal vein is essential.

Portal vein anatomy can be determined noninvasively by 3D CT [118,119] In the current study, the portal vein anatomy was studied both by CECT and by injecting BOSS FLEXSIL GP (Silicone Sealant) in cadaveric liver.

Table 6.2. shows the comparison of branching pattern of the portal vein of various studies with the current radiological study. Of the portal vein anatomy described, the conventional Type 1, in which the main portal vein divides into right and left portal veins was the most commonly encountered branching pattern in previous studies. In the current radiological study conventional type I branching pattern was seen in 89% of the population. Specimens prepared by luminal casting showed that all 15 specimen had conventional type I branching pattern.

Table 6.2. Comparison between present study and other studies showing variations in morphological feature of liver

Portal vein branching patern	Guna-sekaran & Gaba n=100, %	Covey et al., n=200, %	Koc et al., n=1384, %	Sureka et al., n=967, %	Kishi et al., n=361, %	Takeishi et al., n=407, %	Current study n=100, %
Type 1	67	65	75	80	91	89	89
Type 2	10	9	11	7	6	6.1	5
Type 3	6	13	10	5	-	4.7	4
Type 4	1	1	0.5	3	-	-	-
Type 5	8	6	2	1	-	-	1
Miscellaneous	8	6	1.5	4	2.2	49	1

Trifurcation of the portal vein is the second most common type. Kishi et al. reported trifurcation in 6% of the cases, Takeishi et al. in 6.1%, Koc et al. in 11.1% and Sureka et al. in 6.83%, Covey et al in 9% and Gunasekaran and Gaba in 10%.[68,80] In the current study, trifurcation was seen in 5% by radiological study.

Type 3 branching pattern in which there was a separate origin of right posterior portal vein had a separate origin from main portal vein was reported by Takeishi et al. in 4.7%, Koc in 9.7%, Sureka et al in 4.9%, Covey et al in 13% and Gunasekaran and Gaba in 6%[73,74,80,81,120] and in the present radiological study in 4%. In the luminal casting study early segmentation of right posterior segmental division was seen in one specimen (6.6%). In addition, variations like right posterior sectoral division supplying segments IV, V VIII were noted in one specimen. Right posterior sectoral division supplying segment VIII was seen in 46.6%.

Type 4 variation in which portal vein branch to segment VII arises as the first branch of right portal vein was reported by Sureka in 2.69%.[65] This anomaly was not encountered in the present radiological study.

Type 5 variation in which portal branch to segment VI arises as the first branch of right portal vein has been reported Gunasekaran and Gaba in 8 %, Covey et al. in 6 %, Koc et al. in 2%, Sureka et al in 1%[65,80,81,120] and 1% in the present radiological study.

In addition to this, in the current radiological study, a separate branch arising from left portal vein supplying segment VII was also noted. Such anomaly has not been reported earlier. In the luminal casting study other variations of right anterior sectoral division were also noted. They include early segmentation of right anterior segmental division supplying segment VIII and gave branches to segments VI and VII and to segment IV.

Though variation of left portal vein anomalies are rare, in the luminal casting study, variation in one specimen was encountered, where the branch to segment IV also supplied segment V and VIII. Such an anomaly is very rare and has been earlier reported by one author. Koc et al. in their study on 1384 patients reported segment VIII being supplied by left portal vein in 0.8% and segment V supplied both by right and left portal vein in 0.1%.

Knowledge regarding the vascular anatomy and their variation will help the radiologist, surgeons to minimize the iatrogenic complications during various surgical procedure involving the hepatobiliary system.

HIGHLIGHTS OF THE STUDY

7. HIGHLIGHTS OF THE STUDY

This study highlights various variations of the liver in the form of external morphology and the internal branching pattern of the hepatic vasculature.

The morphological variations noted were:

- Presence of fissures in different lobes of the liver, and the highest frequency being observed in the right lobe with an occurrence of 51.43%
- Single or multiple grooves in the anterior surface (11.43%)
- Elongated left lobe (12.86%)
- Underdeveloped caudate process (4.29 %)
- Hypertrophied caudate process (2.86%)
- Enlarged papillary process (4.29%)
- Underdeveloped papillary process (1.43%)
- Quadrate lobe with tongue like projection (7.14%)
- Bilobed quadrate lobe (7.14%)
- Pons hepatis (22.86%)
- Accessory lobe (12.86%)

7.1 Hepatic artery branching pattern

- The conventional extrahepatic branching pattern, where the proper hepatic artery dividing into right and left hepatic arteries was noted in 78% of subjects.
- Of the variations noted, the replaced right hepatic artery seen in 13% of the subjects was the commonest pattern.
- The cystic artery origin from left hepatic artery was noted in 6.6%
- The caudate lobe received its arterial blood supply mainly from right hepatic artery. In 6.6%, it was supplied by left hepatic artery.
- The middle hepatic artery which supplies quadrate lobe/segment IV most often stemmed from left hepatic artery. Variations were noted in 20%, where the middle hepatic artery either arose from the point of bifurcation of the right and left hepatic artery or directly from the right hepatic artery or from the right anterior division of the right hepatic artery.
- In the right lobe, no variation in the arterial supply to segment VI was observed. Variation in the arterial supply to other segments were noted
- There is no variation in the blood supply to segments II, III and IV of the left lobe.

7.2 Portal Vein branching pattern

Radiological study

- In the radiological study the normal anatomy of the portal vein was observed in 89% and the most frequently occurring variations was the type 2 variation, i.e., trifurcation.
- Type 4 and type 5 variations are rare.
- Segment VII supplied by left portal vein was noted in 6.6%.

Luminal casting technique

- In the luminal casting study all the 15 specimens show the conventional type1.
- Variations were noted in the intrahepatic branching pattern.
- Variations were noted in the distribution of portal branch to caudate lobe. It received branches from the left portal vein, from the point of bifurcation of main portal vein into the right and left portal vein, from both the right and left portal vein and also from the left portal vein and bifurcation of main portal vein.
- There were early segmentation of the right portal vein, right anterior division, right posterior division.
- Early segmentation of the right portal vein supplying segment VIII.
- Early segmentation of the right anterior sectoral division supplying segment VIII.
- Early segmentation of right posterior segmental division supplying segment VI.

- A rare variation where the segment VIII did not received its supply from the right portal vein but the vertical portion of the left portal vein in addition to its supply to the segments III and IV, gave off branches to segments V and VIII.
- In one specimen, the segment IV, in addition to its branches from the left portal vein, also received branches from the right anterior sectoral division.

CONCLUSION

8. CONCLUSION

In this study, various morphological variations of liver were observed. The awareness about this will aid the radiologists to make more accurate analysis of the radiological images and thereby aiding in the reduction of the false reports.

This study highlights the intrahepatic branching pattern of the hepatic artery and portal vein. Variations in the segmental supply was observed which has not been studied in detail previously in the Indian population. In both hepatic arterial and portal vein branching patterns, the variations on the left side are infrequent. There was no gender difference in the branching pattern of both hepatic artery and portal vein. A prior knowledge of such variations will help the interventional radiologist to reduce or avoid misinterpretations and subsequent misdiagnosis and help/guide the hepatobiliary surgeon in minimizing iatrogenic complications. It would also allow the surgeons to carry out a structured surgical procedure and bring about an improved and successful post-operative results.

LIMITATIONS

9. LIMITATIONS

For luminal plastination, fresh specimens are preferred. But the specimens used in this study has been preserved in formalin for the last 7 years or so and there is an issue related to the patency of the lumens of the structure to be injected, as most of the vessels were filled with thrombus.

The sample size for luminal casting was not adequate to study about the segmental supply of the liver.

FUTURE SCOPE

10. FUTURE SCOPE

To study the distribution of the intrahepatic course of the biliary system by luminal cast technique and radiological study.

To study the branching pattern of the hepatic veins which forms one of the basis for determining the segments of the liver according to Couinaud's classification of liver anatomy.

BIBLIOGRAPHY

Reference

1. Susan Stranding. Gray,s Anatomy. 40th ed. London, UK: Elsevier; 2008.
2. Van Gulik TM, van den Esschert JW. James Cantlie's early messages for hepatic surgeons: how the concept of pre-operative portal vein occlusion was defined. HPB. 2010 Mar;12(2):81–3.
3. Patil S, Sethi M, Kakar S. Morphological study of human liver and its surgical importance. Int J Anat Res. 2014;2(2):310–4.
4. Shankar N, Rabi S. A rare case of combined hypoplasia of right lobe of the liver and a persistent left umbilical vein. Eur J Anat. 2005;9(1):55–7.
5. Abdel-Misih SRZ, Bloomston M. Liver Anatomy. Surg Clin North Am. 2010 Aug;90(4):643–53.
6. Kamath BK. A study of variant hepatic arterial anatomy and its relevance in current surgical practice. Int J Anat Res. 2015;3(1):947–53.
7. Catalano OA, Singh AH, Uppot RN, Hahn PF, Ferrone CR, Sahani DV. Vascular and biliary variants in the liver: implications for liver surgery. Radiogr Rev Publ Radiol Soc N Am Inc. 2008 Apr;28(2):359–78.
8. Guler N, Dayangac M, Yaprak O, Akyildiz M, Gunay Y, Taskesen F, et al. Anatomical variations of donor portal vein in right lobe living donor liver transplantation: the safe use of variant portal veins. Transpl Int Off J Eur Soc Organ Transplant. 2013 Dec;26(12):1191–7.
9. Cheng YF, Huang TL, Chen CL, Sheen-chen SM, Lui CC, Chen TY, et al. Anatomic dissociation between the intrhepatic bile duct and portal vein:Risk factor for left hepatectomy. World J Surg. 1997;21(3):297–300.
10. Kishi Y, Imamura H, Sugawara Y, Sano K, Kaneko J, Kokudo N, et al. Evaluation of donor vasculobiliary anatomic variations in liver graft procurements. Surgery. 2010 Jan 1;147(1):30–9.
11. Phad V, Syed S., Joshi R. Morphological Variation of Liver. Int J Health Sci Res 2014;4(9):ISSN : 2249-9571.
12. Chaudhari HJ, Ravat MK, Vaniya VH, Bhedi AN. Morphological Study of Human Liver and Its Surgical Importance. J Clin Diagn Res. 2017 Jun;11(6):AC09-AC12.

13. Wahane A, Satpute C. Normal Morphological Variations of Liver Lobes: A Study on Adult Human Cadaveric Liver in Vidarbha Region.IJSR 2015;4(5):2319–7064.
14. Saritha S, Ramani, Nagajyoti, Yesender. Cite As: Cadaveric Study of Morphological Variations in the human liver and its Clinical importance; Int J Med Sci.Clin intervene. 2015;2(6):1020–31.
15. Aktan ZA, Savas, Pinar R, Arslan R. Lobe and Segment Anomalies of the Liver. J Anat Soc. 2001;50(1):15–6.
16. Sangeetha M, Varalakshmi K., Nayak S. A study of the morphometry of liver. Int J Anat Res. 2014;4(8):441–3.
17. Demirci A, Diren HB, Selcuk MB. Computed Tomography in Agenesis of Right Lobe of Liver. Acta Radiologica. 1990;31(1):105–6.
18. Kakitsubata Y, Kakitsubata S, Asada K, Watanabe K. Anomalous right lobe of the liver: CT appearance. Gastrointest Radiol. 1991 Dec 1;16(1):326–8.
19. Radin DR, Colletti PM, Ralls PW, Boswell WD, Halls JM. Agenesis of the right lobe of the liver. Radiology. 1987 Sep;164(3):639–42.
20. Gathwala G, Sen J. Agenesis of the right lobe of liver. Indian J Pediatr. 2003 Feb;70(2):183–4.
21. Hsu KL, Cheng YF, Ko SF. Hypoplastic right hepatic lobe with retrohepatic gallbladder complicated by hepatolithiasis and liver abscess: a case report. Hepatogastroenterology. 1997 Jun;44(15):803–7.
22. Chou CK, Mak CW, Lin MB, Tzeng WS, Chang JM. CT of agenesis and atrophy of the right hepatic lobe. Abdom Imaging. 1998 Dec;23(6):603–7.
23. Kanematsu M, Imaeda T, Yamawaki Y, Doi H. Agenesis of the right lobe of the liver: Case report. Gastrointest Radiol. 1991 Dec 1;16(1):320–2.
24. Morpi-Ett A, Adam A. Agenesis of the Right Lobe of the Liver: Diagnosis by Computed Tomography. Australas Radiol. 1992 Feb 1;36(1):68–9.
25. Nikam VR, Kitture BS. Agenesis of right lobe of liver; a rare anomaly: a case report. Int J Res Med Sci. 2017 Jan 5;3(1):345–8.

26. Vinnakota S, Jayasree N. A New Insight into the Morphology of the Human Liver: A Cadaveric Study.Int Sci Res Notices 2013. Available from:https://hindawicom/journals/isrn/2013 /689564/

27. Nayak SB, Kumar N, Sirasanagandla SR, Shetty SD. A mini accessory liver lobe in the fissure for ligamentum teres and its clinical significance: a case report. J Clin Diagn Res . 2013 Nov;7(11):2573–4.

28. Mamatha Y, Murthy CK, Prakash B. Study on Morphological Surface Variations In Human Liver. Int J Health Sci Res. 2014;4(11):ISSN : 2249-9571.

29. Shivarama C, Kumar A. Spatular Extension of Left Lobe of Liver : A Case Report. Int J Sci.Res.Eng Int J Sci Res Eng. 2015;3(1):2845–8.

30. Abraham J, V AK, Palatty UB. Surface Variations of Caudate Lobe and Its Clinical Implications. -. Int J Health Sci Res. 2015;5(6):236–40:980-3

31. Sarala HS, Jyothilakshmi TK, Shubha R. Morphological Variations of Caudate Lobe of the Liver and their Clinical Implications. Int J Anat Res 2015;3(2):

32. Chavan N, Wabale R. Morphological study of caudate lobe of liver. IJBAMR. 2014;3(3):204–11.

33. Singh R. Hypoplastic Left Lobe of Liver with Accessory Caudate Lobe . Case Rep Med. 2013. Available from: https://www.hindawi.com/journals/crim/2013/604513/

34. Khedekar DN, Hattangdi SS. Some interesting morphological features of liver lobes in Mumbai population. Int J Med Res Health Sci. 2014;3(3):656.

35. Khedekar DN, Hattangdi SS. Some interesting morphological features of liver lobes in Mumbai population. Int J Med Res Health Sci. 2014;3(3):656.

36. Kogure K, Kuwano H, Fujimaki N, Makuuchi M. Relation among portal segmentation, proper hepatic vein, and external notch of the caudate lobe in the human liver. Ann Surg. 2000;231(2):223.

37. Maharana SS, Sharma A, Kumarhatti SHP. Accessory liver a rare finding: a cadaveric study.; Available from: http://www.ijpaes.com/admin/php/uploads/851.

38. Sato S, Watanabe M, Nagasawa S, Niigaki M, Sakai S, Akagi S. Laparoscopic observations of congenital anomalies of the liver. Gastrointest Endosc. 1998 Feb 1;47(2):136–40.

39. Muktyaz H, Nema U, Suniti MiR, Mahboobul H. Anatomical study of Accessory Sulci of Liver and its Clinical Significance in North Indian Population. Int J Med Health Sci. 2013;2(2):224–9.

40. McNulty J. Congenital and hereditary disorders of the liver. In Radiology of the Liver. 1977;164–5.

41. Savopoulos C, Kakaletsis N, Kaiafa G, Iliadis F, Kalogera-Fountzila A, Hatzitolios AI. Riedel's Lobe of the Liver: a case report. Medicine (Baltimore) . 2015 /; 94(3): e430

42. Salzman SM, Schroff E, Goldman MD. Riedel Fight Song : a case report of riedel lobe presumed to be hepatomegaly. Int J Contemp Pediatr. 2016;3(3):1089–91.

43. Gillard JH, Patel MC, Abrahams PH, Dixon AK. Riedel's lobe of the liver: fact or fiction? Clin Anat. 1998;11(1):47–9.

44. Elmasalme F, Aljudaibi A, Matbouly S, Hejazi N, Zuberi MSH. Torsion of an accessory lobe of the liver in an infant. J Pediatr Surg. 1995 Sep 1;30(9):1348–50.

45. Macdonald DB, Haider MA, Khalili K, Kim TK, O'Malley M, Greig PD, et al. Relationship between vascular and biliary anatomy in living liver donors. AJR Am J Roentgenol. 2005 Jul;185(1):247–52.

46. Schroeder T, Radtke A, Kuehl H, Debatin JF, Malagó M, Ruehm SG. Evaluation of Living Liver Donors with an All-inclusive 3D Multi–Detector Row CT Protocol. Radiology. 2006 Mar 1;238(3):900–10.

47. Uchida K, Taniguchi M, Shimamura T, Suzuki T, Yamashita K, Ota M, et al. Three-dimensional computed tomography scan analysis of hepatic vasculatures in the donor liver for living donor liver transplantation. Liver Transplant Off Publ Am Assoc Study Liver Dis Int Liver Transplant Soc. 2010 Sep;16(9):1062–8.

48. Aristotle S. Variations in origin and course of cystic artery and its relation to Calots triangle with its clinical implications. OA Anatomy. 2014;2(17):1–3.

49. Williams P L, Warwick R., Dyson M, Bannister LH. Gray's anatomy. 37th.ed. Edinburgh: Churchill Livingstone; 1989.
50. Balija M, Huis M, Nikolić V, Štulhofer M. Laparoscopic Visualization of the Cystic Artery Anatomy. World J Surg. 1999 Jul 1;23(7):703–7.
51. Nowak. Variation of the cystic artery in man.Folia Morphol (Warsz). 1977;36(2):89-98
52. Ding Y. New classification of the anatomic variations of the cystic artery during laparoscopic cholecystectomy. World J Gastroenterol. 2007;13(42):5629–34.
53. Hugh T. Laparoscopic anatomy of the cystic artery. Am J Surg. 1992;163(6):593–5.
54. Ghosh SK. Variations in the origin of middle hepatic artery: a cadaveric study and implications for living donor liver transplantation. Anat Cell Biol. 2014 Sep;47(3):188–95.
55. Michels NA. Newer anatomy of the liver and its variant blood supply and collateral circulation. Am J Surg. 1966 Sep 1;112(3):337–47.
56. Reuter S, Redman H. Gastrointestinal Angiography. 2nd edn. W.B Saunders Company. 1977. 31-33 p.
57. Munshi I, Daniel F, David T, Robert K J, James P, Richard B W. Occlussion of an Aberrant Right Hepatic Artery, Originating from Superior Mesenteric Artery, Second to Blunt Trauma. J Trauma. 2000;48(2):325-6
58. Rela M, McCall JL, Karani J, Heaton ND. Accessory right hepatic artery arising from the left: implications for split liver transplantation. Transplantation. 1998;66(6):792–794.
59. Hiatt JR, Gabbay J, Busuttil RW. Surgical anatomy of the hepatic arteries in 1000 cases. Ann Surg. 1994 Jul;220(1):50–2.
60. Ugurel MS, Battal B, Bozlar U, Nural MS, Tasar M, Ors F, et al. Anatomical variations of hepatic arterial system, coeliac trunk and renal arteries: an analysis with multidetector CT angiography. Br J Radiol. 2010 Aug;83(992):661–7.

61. Chen CY, Lee RC, Tseng HS, Chiang JH, Hwang JI, Teng MM. Normal and variant anatomy of hepatic arteries: angiographic experience. Zhonghua Yi Xue Za Zhi Chin Med J Free China Ed. 1998 Jan;61(1):17–23.

62. Kamel IR, Kruskal JB, Pomfret EA, Keogan MT, Warmbrand G, Raptopoulos V. Impact of multidetector CT on donor selection and surgical planning before living adult right lobe liver transplantation. Am J Roentgenol. 2001 Jan;176(1):193–200.

63. Ramanadham S, Toomay SM, Yopp AC, Balch GC, Sharma R, Schwarz RE, et al. Rare Hepatic Arterial Anatomic Variants in Patients Requiring Pancreatoduodenectomy. Case Rep Surg. 2012/953195

64. Lopez-Andujar. Lessons learned from anatomic variants of the hepatic artery in 1,081 transplanted livers. Liver Transpl. 2007;13(10):1401–4.

65. Sureka B. Variations of celiac axis, common hepatic artery and its branches in 600 patients. Indian J Radiol Imaging. 2013;23(3):223–33.

66. Suganthy J, Jacob T, Agarwal R. Multiple Vascular Variation of Splanchnic Branches of Abdominal Aorta In A 103 Year Old South Indian Male: A Case Report. J Anat Soc. 2008;57(1):37–42.

67. Yan J, Tokunaga K, Takahashi H, Hitomi J. Multiple arteries supplying the human liver: A case report of a rare variation of the blood supplying pattern in a Japanese population. Edorium J Anat Embryo. 2015;2:1–5.

68. Covey AM, Brody LA, Getrajdman GI, Sofocleous CT, Brown KT. Incidence, Patterns, and Clinical Relevance of Variant Portal Vein Anatomy. Am J Roentgenol. 2004 Oct 1;183(4):1055–64.

69. Noussios G, Dimitriou I, Chatzis I, Katsourakis A. The Main Anatomic Variations of the Hepatic Artery and Their Importance in Surgical Practice: Review of the Literature. J Clin Med Res. 2017 Apr;9(4):248–52.

70. Shukla PJ, Barreto SG, Kulkarni A, Nagarajan G, Fingerhut A. Vascular anomalies encountered during pancreatoduodenectomy: do they influence outcomes? Ann Surg Oncol. 2010 Jan;17(1):186–93.

71. Koops A, Wojciechowski B, Broering DC, Adam G, Krupski-Berdien G. Anatomic variations of the hepatic arteries in 604 selective celiac and superior mesenteric angiographies. Surg Radiol Anat SRA. 2004 Jun;26(3):239–44.

72. Oran I, Yesildag A, Memis A. Aortic origin of right hepatic artery and superior mesenteric origin of splenic artery two rare variations demonstrated angiographically. Surg Radiol Anat. 2001 Dec 1;23(5):349–52.

73. Takeishi K, Shirabe K, Yoshida Y, Tsutsui Y, Kurihara T, Kimura K, et al. Correlation Between Portal Vein Anatomy and Bile Duct Variation in 407 Living Liver Donors. Am J Transplant. 2015 Jan 1;15(1):155–60.

74. Sureka B, Patidar Y, Bansal K, Rajesh S, Agrawal N, Arora A. Portal vein variations in 1000 patients: surgical and radiological importance. Br J Radiol. 2015 Nov;88(1055):20150326.

75. Alghamdi T, Viebahn C, Justinger C, Lorf T. Arterial Blood Supply of Liver Segment IV and Its Possible Surgical Consequences. Am J Transplant. 2017 Apr;17(4):1064–70.

76. Blumgart L.H, Fong Y. Surgery of the liver and biliary tract. 3rd ed. WB Saunaders Company LTD; 2000. 1640-1645 p.

77. Kishi Y. Evaluation of donor vasculobiliary anatomic variations in liver graft procurements -. J.Surg. 2010;147(1):30–9.

78. Sadler TW Langman's Medical Embryology. 12th ed;Lippincott Williams & wilkins. 2013.

79. Guler N, Dayangac M, Yaprak O, Akyildiz M, Gunay Y, Taskesen F, et al. Anatomical variations of donor portal vein in right lobe living donor liver transplantation: the safe use of variant portal veins. Transpl Int. 2013 Dec 1;26(12):1191–7.

80. Gunasekaran SS, Gaba RC. Anatomic Variations of the Right Portal Vein: Prevalence, Imaging Features, and Implications for Successful Transjugular Intrahepatic Portosystemic Shunt Creation. J Clin Imaging Sci. 2017 Jan 1;7(1):14.

81. Koc Z. Portal vein variations:clinical implications and frequencies in routine abdomibnal multidetector CT. Diagn Interv Radiol. 2007;13(2):75–80.

82. Sakai H, Okuda K, Yasunaga M, Kinoshita H, Aoyagi S. Reliability of hepatic artery configuration in 3D CT angiography compared with conventional angiography – special reference to living-related liver transplant donors. Transpl Int. 2005 May 1;18(5):499–505.

83. Mishra S, Sethi M. A Reformed Corrosion Cast Technique using Commercially Available Polyvinyl Chloride Solution. MAMC J Med Sci. 2015 Jan 1;1(1):28.

84. Laishram D, T S. A study of Tracheobronchial Tree Using Luminal Cast Plastination. IOSR J . Dent Med Sci 2017;16(4):5–8.

85. De Sordi N, Bombardi C, Chiocchetti R, Clavenzani P, Trerè C, Canova M, et al. A new method of producing casts for anatomical studies. Anat Sci Int. 2014 Sep;89(4):255–65.

86. Jin GY, Yu HC, Lim H-S, Moon JI, Lee JH, Chung JW, et al. Anatomical variations of the origin of the segment 4 hepatic artery and their clinical implications. Liver Transpl. 2008 Aug 1;14(8):1180–4.

87. Jurkovikj D. New variant liver surface morphology according to portal vein segmentation. IJAPSA. 2016;2(10):ISSN : 2394-823X.

88. Joshi SD, Joshi SS, Athavale SA. Some interesting observations on the surface features of the liver and their clinical implications. Singapore Med J. 2009 Jul;50(7):715–9.

89. Macchi V, Feltrin G, Parenti A, De Caro R. Diaphragmatic sulci and portal fissures. J Anat. 2003 Mar;202(3):303–8.

90. Auh Y, Rubenstein W, Zirinsky K, Kneeland J, Pardes J, Engel I, et al. Accessory fissures of the liver: CT and sonographic appearance. Am J Roentgenol. 1984 Sep 1;143(3):565–72.

91. Nagato AC, Silva MAS, Trajano ETL ,Alves JN, Bandeira ACB, Ferreira TA, Valenca SS, Bezerra FS. Quantitative and mophological analysis of different types of liver. J Morphol Sci. 2011;28(4):275–9.
92. Pujari BD, Deodhare SG. Symptomatic accessory lobe of liver with a review of the literature. Postgrad Med J. 1976 Apr;52(606):234–6.
93. Saxena A, Agarwal K kumar, Jakhwal C, Singh S, Das AR. Some Variable Facts of Liver: Embryological and Clinical Perspective. IJARS 2016;5(1):64–7.
94. Phad VV, Syed SA, Joshi RA. Morphological Variations of Liver. Int J Health Sci Res 2014;4(9):119–124.
95. Collan Y, Hakkiluoto A, Hastbacka J. Ectopic liver. Ann Chir Gynaecol. 1978;67(1):27–9.
96. Massaro M, Valencia MP, Guzman M, Mejia J. Accessory hepatic lobe mimicking an intra-abdominal tumor. J Comput Assist Tomogr. 2007 Aug;31(4):572–3.
97. Satheesha B N, D R, BM G, S M. Accessory Lobe of Liver Associated with a “Bean Shaped” Gall Bladder. Kathmandu Univ Med J. 2016;14(55):292–3.
98. Chaib E, Ribeiro MAF, Saad WA, Gama-Rodrigues J. The Main Hepatic Anatomic Variations for the Purpose of Split-Liver Transplantation. Transplant Proc. 2005 Mar 1;37(2):1063–6.
99. Jones RM, Hardy KJ. The hepatic artery: a reminder of surgical anatomy. J R Coll Surg Edinb. 2001 Jun;46(3):168–70.
100. Lin and Chaikof. Embryology, anatomy, and surgical exposure of the great abdominal vessels. Surg Clin North Am. 2000;80(1):417–33.
101. Stauffer JA, Bridges MD, Turan N, Nguyen JH, Martin JK. Aberrant right hepatic arterial anatomy and pancreaticoduodenectomy: recognition, prevalence and management. HPB. 2009 Mar;11(2):161–5.
102. Yang F, Long J, Fu D-L, Jin C, Yu X-J, Xu J, et al. Aberrant Hepatic Artery in Patients Undergoing Pancreaticoduodenectomy. Pancreatology. 2008 Apr 1;8(1):50–4.

103. Furuta T, Maeda E, Akai H, Hanaoka S, Yoshioka N, Akahane M, et al. Hepatic Segments and Vasculature: Projecting CT Anatomy onto Angiograms. RadioGraphics. 2009 Nov 1;29(7):e37.
104. Miyayama S. Hepatocellular carcinoma in the caudate lobe of the liver:variations of its feeding branches on arteriography. Jpn J Radiol. 2010;28:555–62.
105. Miyayama S. Angiographic anatomy of arterial branches to the caudate lobe of liver with special reference to its effect on transarterial embolization of hepatocelluar carcinoma. Clinical Radiography. 1990;35(3):353–9.
106. Alghamdi T. Arterial Blood Supply of Liver Segment IV and Its Possible Surgical Consequences. Am J Transplant. 2017;17(4):1064–70.
107. Hiatt J. Surgical Anatomy of the Hepatic Arteries in 1000 Cases. Ann Surg. -1994;220(1):50–2.
108. Wang S, He X, Li Z, Peng Z, Tam NL, Sun C, et al. Characterization of the middle hepatic artery and its relevance to living donor liver transplantation. Liver Transplant Off Publ Am Assoc Study Liver Dis Int Liver Transplant Soc. 2010 Jun;16(6):736–41.
109. Onishi H, Kawarada Y, Das BC, Nakano K, Gadzijev EM, Ravnik D, et al. Surgical anatomy of the medial segment (S4) of the liver with special reference to bile ducts and vessels. Hepato-gastroenterol. 2000 Feb;47(31):143–50.
110. Kishi Y, Sugawara Y, Kaneko J, Akamatsu N, Imamura H, Asato H, et al. Hepatic arterial anatomy for right liver procurement from living donors. Liver Transpl. 2004 Jan 1;10(1):129–33.
111. Futara G, Ali A, Kinfu Y. Variations of the hepatic and cystic arteries among Ethiopians. Ethiop Med J. 2001 Apr;39(2):133–42.
112. Fan S-T, Lo C-M, Liu C-L, Wang W-X, Wong J. Safety and Necessity of Including the Middle Hepatic Vein in the Right Lobe Graft in Adult-to-Adult Live Donor Liver Transplantation. Ann Surg. 2003 Jul;238(1):137–48.
113. Suehiro T, Ninomiya M, Shiotani S, Hiroshige S, Harada N, Ryosuke M, et al. Hepatic artery reconstruction and biliary stricture formation after living donor adult liver transplantation using the left lobe. Liver Transpl. 2002 May 1;8(5):495–9.

114. Shimada M, Shiotani S, Ninomiya M, Terashi T, Hiroshige S, Minagawa R, et al. Characteristics of Liver Grafts in Living-Donor Adult Liver Transplantation: Comparison Between Right- and Left-Lobe Grafts. Arch Surg. 2002 Oct 1;137(10):1174–9.

115. Erbay N, Raptopoulos V, Pomfret EA, Kamel IR, Kruskal JB. Living Donor Liver Transplantation in Adults: Vascular Variants Important in Surgical Planning for Donors and Recipients. Am J Roentgenol. 2003 Jul 1;181(1):109–14.

116. Schroeder T, Malagó M, Debatin JF, Testa G, Nadalin S, Broelsch CE, et al. Multidetector computed tomographic cholangiography in the evaluation of potential living liver donors. Transplantation. 2002 Jun 27;73(12):1972–3.

117. Hiraoki S, Shigeaki S, Kimura F, Hiroyuki Y, Masayuki O, Atshushi K, et al. Clinical Significance of Biliary Vascular Anatomy of the Right Liver for Hilar Cholangiocarcinoma Applied to Left Hemihepatectomy. Ann Surg. 2009;249(3):435–9.

118. Bogetti JD, Herts BR, Sands MJ, Carroll JF, Vogt DP, Henderson JM. Accuracy and utility of 3-dimensional computed tomography in evaluating donors for adult living related liver transplants. Liver Transplant Off Publ Am Assoc Study Liver Dis Int Liver Transplant Soc. 2001 Aug;7(8):687–92.

119. Suzuki H, Shibamoto Y, Oshima H, Takeuchi M, Ito M, Hara M. Comparison of 2 contrast materials with different iodine concentrations in 3-dimensional computed tomography angiography of the hepatic artery at multi-detector-row computed tomography: a randomized study. J Comput Assist Tomogr. 2007 Dec;31(6):840–5.

120. Covey AM. incidence, patterns, and clinical relevance of variant portal anatomy. Am J Roentgenol. 2004;183(4):1055–64.

APPENDIX

OFFICE OF RESEARCH
INSTITUTIONAL REVIEW BOARD (IRB)
CHRISTIAN MEDICAL COLLEGE, VELLORE, INDIA

Dr. B.J. Prashantham, M.A., M.A., Dr. Min (Clinical)
Director, Christian Counseling Center,
Chairperson, Ethics Committee.

Dr. Alfred Job Daniel, D Ortho MS Ortho DNB Ortho.
Chairperson, Research Committee & Principal

Dr. Nihal Thomas,
MD, MNAMS, DNB (Endo), FRACP (Endo), FRCP (Edin), FRCP (Glasg)
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)

December 15, 2015

Dr. Haobam Rajajee Singh,
PG Registrar,
Department of Anatomy,
Christian Medical College,
Vellore 632 004.

Sub: **Fluid Research grant project NEW PROPOSAL:**
Study of the Anatomical variations of the liver in Human.
Dr. Haobam Rajajee Singh, Emp. No: 21217, PG Registrar, Anatomy, Dr. Suganthy J, Emp. No: 30085, Professor and Head, Dr. Minu Rekha B. Emp. No: 32928, Assistant professor Dept. of Anatomy, Dr. Reetu Amrita John Emp. No: 28729, Dept. of Radio diagnosis, Dr. Manbha Rymbai Emp. No: 51919, Assistant Surgeon, Department of Hepatopancreato biliary Surgery, Dr. Devakumar Devadhas (Emp. No: 30045, Associate professor, Department of Nuclear Medicine, Mr. Prakash R. Emp. No: 33835, senior demonstrator, Department of Biostatistics.

Ref: IRB Min No: 9718 [OBSERVE] dated 10.11.2015

Dear Dr. Haobam Rajajee Singh,
The Institutional Review Board (Blue, Research and Ethics Committee) of the Christian Medical College, Vellore, reviewed and discussed your project titled "Study of the Anatomical variations of the liver in Human" on November 10th 2015.

I enclose the following documents:-
1. Institutional Review Board approval 2. Agreement

Could you please sign the agreement and send it to Dr. Nihal Thomas, Addl. Vice Principal (Research), so that the grant money can be released.

With best wishes,

Dr. Nihal Thomas
Secretary (Ethics Committee)
Institutional Review Board

Dr. NIHAL THOMAS
MD, MNAMS, DNB(Endo), FRACP(Endo), FRCP(Edin), FRCP(Glasg)
SECRETARY - (ETHICS COMMITTEE)
Institutional Review Board
Christian Medical College, Vellore

Cc: Dr. Suganthy J, Dept. of Anatomy, CMC

Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002
Tel: 0416 – 2284294, 2284202 Fax: 0416 – 2262788, 2284481 E-mail: research@cmcvellore.ac.in

OFFICE OF RESEARCH
INSTITUTIONAL REVIEW BOARD (IRB)
CHRISTIAN MEDICAL COLLEGE, VELLORE, INDIA

Dr. B.J. Prashantham, M.A., M.A., Dr. Min (Clinical)
Director, Christian Counseling Center,
Chairperson, Ethics Committee.

Dr. Alfred Job Daniel, D Ortho MS Ortho DNB Ortho.
Chairperson, Research Committee & Principal

Dr. Nihal Thomas,
MD, MNAMS, DNB (Endo), FRACP (Endo), FRCP (Edin), FRCP (Glasg)
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)

December 15, 2015

Dr. Haobam Rajajee Singh,
PG Registrar,
Department of Anatomy,
Christian Medical College,
Vellore 632 004.

Sub: **Fluid Research grant project NEW PROPOSAL:**
Study of the Anatomical variations of the liver in Human.
Dr. Haobam Rajajee Singh, Emp. No: 21217, PG Registrar, Anatomy, Dr. Suganthy J, Emp. No: 30085, Professor and Head, Dr. Minu Rekha B. Emp. No: 32928, Assistant professor Dept. of Anatomy, Dr. Reetu Amrita John Emp. No: 28729, Dept. of Radio diagnosis, Dr. Manbha Rymbai Emp. No: 51919, Assistant Surgeon, Department of Hepatopancreato biliary Surgery, Dr. Devakumar Devadhas (Emp. No: 30045, Associate professor, Department of Nuclear Medicine, Mr. Prakash R. Emp. No: 33835, senior demonstrator, Department of Biostatistics.

Ref: IRB Min No: 9718 [OBSERVE] dated 10.11.2015

Dear Dr. Haobam Rajajee Singh,
The Institutional Review Board (Blue, Research and Ethics Committee) of the Christian Medical College, Vellore, reviewed and discussed your project titled "Study of the Anatomical variations of the liver in Human" on November 10th 2015.

The Committee reviewed the following documents:

1. IRB Application format
2. Proforma
3. Cvs of Drs. Suganthy J, Devakumar Devadhas, Minu Rekha B, Haobam Rajajee Singh, Reetu Amrita John, Manbha Rymbai, Mr. Prakash R
4. No. of documents 1 - 3

The following Institutional Review Board (Blue, Research & Ethics Committee) members were present at the meeting held on November 10th 2015 in the CREST/SACN Conference Room, Christian Medical College, Bagayam, Vellore 632002.

Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002
Tel: 0416 – 2284294, 2284202 Fax: 0416 – 2262788, 2284481 E-mail: research@cmcvellore.ac.in

Dr. B.J. Prashantham, M.A., M.A., Dr. Min (Clinical)
Director, Christian Counseling Center,
Chairperson, Ethics Committee.

Dr. Alfred Job Daniel, D Ortho MS Ortho DNB Ortho.
Chairperson, Research Committee & Principal

Dr. Nihal Thomas,
MD, MNAMS, DNB (Endo), FRACP (Endo), FRCP (Edin), FRCP (Glasg)
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)

Name	Qualification	Designation	Affiliation
Dr. Nihal Thomas	MD, MNAMS, DNB(Endo), FRACP (Endo) FRCP(Edin) FRCP (Glasg)	Professor & Head, Endocrinology. Additional Vice Principal (Research), Deputy Chairperson(Research Chairperson), Member Secretary (Ethics Committee), IRB. CMC, Vellore	Internal, Clinician
Dr. Vivek Mathew	MD (Gen. Med.) DM (Neuro) Dip. NB (Neuro)	Professor, Neurology, CMC, Vellore	Internal, Clinician
Dr. Mathew Joseph	MBBS, MCH	Professor, Neurosurgery, CMC, Vellore	Internal, Clinician
Dr. Chandrasingh	MS, MCH, DMB	Professor, Urology, CMC, Vellore	internal, Clinician
Dr. Balamugesh	MBBS, MD(Int Med), DM, FCCP (USA)	Professor, Pulmonary Medicine, CMC, Vellore	Internal, Clinician
Rev. Joseph Devaraj	BSc, BD	Chaplaincy Department, CMC, Vellore	Internal, Social Scientist
Dr. Rajesh Kannangai	MD, PhD.	Professor, Clinical Virology, CMC, Vellore	Internal, Clinician
Dr. Niranjan Thomas	DCH, MD, DNB (Paediatrics)	Professor, Neonatology, CMC, Vellore	Internal, Clinician
Dr. Inian Samarasam	MS, FRCS, FRACS	Professor, Surgery, CMC, Vellore	Internal, Clinician
Dr. B. J. Prashantham	MA(Counseling Psychology), MA(Theology), Dr. Min(Clinical Counselling)	Chairperson, Ethics Comm IRB. Director, Christian Counse Centre, Vellore	External, Social Scientist

Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002
Tel: 0416 – 2284294, 2284202 Fax: 0416 – 2262788, 2284481 E-mail: research@cmcvellore.ac.in

Dr. B.J. Prashantham, M.A., M.A., Dr. Min (Clinical)
Director, Christian Counseling Center,
Chairperson, Ethics Committee.

Dr. Alfred Job Daniel, D Ortho MS Ortho DNB Ortho.
Chairperson, Research Committee & Principal

Dr. Nihal Thomas,
MD, MNAMS, DNB (Endo), FRACP (Endo), FRCP (Edin), FRCP (Glasg)
Deputy Chairperson,
Secretary, Ethics Committee, IRB
Additional Vice-Principal (Research)

Dr. Ratna Prabha	MBBS, MD	Associate Professor, Clinical Pharmacology CMC, Vellore	Internal, Pharmacologist
Dr. Jayaprakash Muliyil	BSc, MBBS, MD, MPH, Dr PH (Epid), DMHC	Retired Professor, CMC, V	External, Scientist &Epidem
Mrs. Emily Daniel	MSc Nursing	Professor, Medical Surgica Nursing, CMC, Vellore	Internal, Nurse
Ms. Grace Rebecca	MSc (Biostatistics)	Lecturer, Biostatistics, CMC, Vellore	Internal, Statistician
Mr. C. Sampath	BSc, BL	Advocate, Vellore	External, Legal Expert
Dr. Anuradha Rose	MBBS, MD, MHSC (Bioethics)	Associate Professor, Comn Health, CMC, Vellore	Internal, Clinician

We approve the project to be conducted as presented.

Kindly provide the total number of patients enrolled in your study and the total number of withdrawals for the study entitled: "Study of the Anatomical variations of the liver in Human" on a monthly basis. Please send copies of this to the Research Office (research@cmcvellore.ac.in)

Fluid Grant Allocation:

A sum of Rs.40,000/- INR (Rupees Forty Thousand Only) will be granted for 2 years.

Yours sincerely

Dr. Nihal Thomas
Secretary (Ethics Committee)
Institutional Review Board

Dr. NIHAL THOMAS
MD, MNAMS, DNB(Endo), FRACP(Endo), FRCP(Edin), FRCP(Glasg)
SECRETARY - (ETHICS COMMITTEE)
Institutional Review Board,
Christian Medical College, Vellore - 632 002.

IRB Min No: 9718 [OBSERVE] dated 10.11.2015

Ethics Committee Blue, Office of Research, 1st Floor, Carman Block, Christian Medical College, Vellore, Tamil Nadu 632 002
Tel: 0416 – 2284294, 2284202 Fax: 0416 – 2262788, 2284481 E-mail: research@cmcvellore.ac.in

Study on anatomical variations of human liver

No.	Surface	Fissure for ligamentumteres	Fissure for ligamentumvenosum	Border	Caudate lobe	Quadrate lobe	Accessory fissure	Accessory lobe	Pons hepatis (connecting left lobe and quadrate lobe)

```
-------------------------------------------------------------
name:  <unnamed>
log:  C:\Users\Biostatistics\Documents\results_aug08.log
log type:  text
opened on:   8 Aug 2017, 11:31:41
. tab1 gender ha_new pv_new

-> tabulation of gender
     Gender |      Freq.     Percent        Cum.
------------+-----------------------------------
     Female |         45       44.55       44.55
       Male |         56       55.45      100.00
------------+-----------------------------------
      Total |        101      100.00

-> tabulation of ha_new
 RECODE of ha (Hepatic |
               Artery) |      Freq.     Percent        Cum.
-----------------------+-----------------------------------
                normal |         78       78.00       78.00
  CHA arising from SMA |          1        1.00       79.00
                   LHA |          4        4.00       83.00
                   RHA |         13       13.00       96.00
Accessory LHA from LGA |          3        3.00       99.00
       Early branching |          1        1.00      100.00
-----------------------+-----------------------------------
                 Total |        100      100.00

-> tabulation of pv_new

  RECODE of |
 pv (Portal |
      vein) |      Freq.     Percent        Cum.
------------+-----------------------------------
     Type 1 |         89       89.00       89.00
     Type 2 |          5        5.00       94.00
     Type 3 |          4        4.00       98.00
     Type 5 |          1        1.00       99.00
      Type6 |          1        1.00      100.00
------------+-----------------------------------
      Total |        100      100.00

.
. tab ha_new gender, chi2 col exact

+-------------------+
| Key               |
|-------------------|
|     frequency     |
| column percentage |
+-------------------+
```

```
Enumerating sample-space combinations:
stage 6:  enumerations = 1
stage 5:  enumerations = 2
stage 4:  enumerations = 3
stage 3:  enumerations = 5
stage 2:  enumerations = 9
stage 1:  enumerations = 0

RECODE of ha (Hepatic |        Gender
              Artery) |    Female       Male |     Total
----------------------+----------------------+----------
               normal |        33         44 |        77
                      |     75.00      81.48 |     78.57
----------------------+----------------------+----------
 CHA arising from SMA |         0          1 |         1
                      |      0.00       1.85 |      1.02
----------------------+----------------------+----------
                  LHA |         3          1 |         4
                      |      6.82       1.85 |      4.08
----------------------+----------------------+----------
                  RHA |         5          7 |        12
                      |     11.36      12.96 |     12.24
----------------------+----------------------+----------
Accessory LHA from LG |         2          1 |         3
                      |      4.55       1.85 |      3.06
----------------------+----------------------+----------
      Early branching |         1          0 |         1
                      |      2.27       0.00 |      1.02
----------------------+----------------------+----------
                Total |        44         54 |        98
                      |    100.00     100.00 |    100.00

          Pearson chi2(5) =   4.2621   Pr = 0.512
           Fisher's exact =                 0.568

. tab pv_new gender, chi2 col exact

+--------------------+
| Key                |
|--------------------|
|     frequency      |
| column percentage  |
+--------------------+

Enumerating sample-space combinations:
stage 5:  enumerations = 1
stage 4:  enumerations = 2
stage 3:  enumerations = 3
stage 2:  enumerations = 4
stage 1:  enumerations = 0
```

```
 RECODE of |
pv (Portal |        Gender
     vein) |    Female       Male |     Total
-----------+----------------------+----------
    Type 1 |        41         46 |        87
           |     91.11      86.79 |     88.78
-----------+----------------------+----------
    Type 2 |         3          2 |         5
           |      6.67       3.77 |      5.10
-----------+----------------------+----------
    Type 3 |         1          3 |         4
           |      2.22       5.66 |      4.08
-----------+----------------------+----------
    Type 5 |         0          1 |         1
           |      0.00       1.89 |      1.02
-----------+----------------------+----------
     Type6 |         0          1 |         1
           |      0.00       1.89 |      1.02
-----------+----------------------+----------
     Total |        45         53 |        98
           |    100.00     100.00 |    100.00

          Pearson chi2(4) =   2.8533   Pr = 0.583
           Fisher's exact =                 0.757

. univar age
                        -------------- Quantiles --------------
Variable   n  Mean  S.D.   Min    .25   Mdn     .75      Max
-------------------------------------------------------------------
    age 100 45.37 14.67  8.00 33.50    45.00   56.00    86.00
-------------------------------------------------------------------

. log close
      name:  <unnamed>
       log:
C:\Users\Biostatistics\Documents\results_aug08.log
  log type:  text
 closed on:   8 Aug 2017, 11:31:43
-------------------------------------------------------------------
```